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GASP - GENERAL AVIATION SYNTHESIS PROGRAM

NASA-CR-152303

VOLUME IV - PROPULSION

PART 1 - THEORETICAL DEVELOPMENT

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FOREWORD

The General Aviation Synthesis Program (GASP) was initially developed by engineers in the Mission Analysis Division at the National Aeronautics and Space Administration's Ames Research Center, Moffett Field, California. Improvements continue to be implemented by individuals in the V/STOL Systems Technology Branch at Ames. Those people providing the major development contributions are

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The NASA technical monitor for the documentation was Mr. T. L. Galloway. The Aerophysics Research Corporation project leader was Mr. D. S. Hague. The GASP program has been used by a number of companies and universities through NASA contracted studies and is under continuing development. Prospective users should consult NASA's Ames Research Center regarding the latest details of the computer code.

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IV.1 PROPULSION

Propulsion system performance is computed during engine sizing and whenever aircraft performance is computed. Two separate sets of propulsion subroutines are used for jet and propeller driven aircraft as illustrated in Figure IV.1.1.

IV.1.1 Turbojet/Fan Propulsion Subroutines

The turbofan/turbojet engine performance methodology is based on tabulated performance data for specific engine cycles. Currently, seven different engine cycles are available representing a wide range of operational and conceptual engines. Data for these engines are contained in subroutines ENGDT1-7. Tabular engine data for turbofan/turbojet engines may also be input in which case ENGDTT is used to determine engine performance.

Performance data for each of the engine cycles may be scaled up or down to simulate an engine of arbitrary size. Engine size is expressed in terms of sea level static airflow and is determined in subroutine ENGSZ. Engine performance is determined by subroutine ENGINE as a function of the flight altitude, Mach number, and engine power setting.

ENGSZ determines the engine size necessary to meet selected performance requirements. The engine size is expressed in terms of rated airflow under normal sea level static conditions. The engine is first sized to match cruise drag, with an option to specify a rate of climb margin. An option is then provided to resize the engine so as to match a required takeoff distance or to match one-engine-out requirements on the aircraft rate of climb (FAR, Part 23 or Part 25.).

TURBOFAN	PROPELLER
ENGSZ (510) DETERMINES ENGINE SIZE	ENGSZ (615) DETERMINES ENGINE SIZE
ENGINE (110) ENGINE PERFORMANCE	ENGINE (480) POWER PLANT PERFORMANCE
ENGDT1 (50) ENGINE DATA	PWRPLT (65) RECIPROCATING ENGINE PERFORMANCE
ENGDT2 (80) ENGINE DATA	TURBEG (270) TURBOPROP ENGINE PERFORMANCE
ENGDT3 (70) ENGINE DATA	ENGDAT (120) PROPELLER CHARACTERISTICS
ENGDT4 (70) ENGINE DATA	PERFM (490) PROPELLER PERFORMANCE
ENGDT5 (70) ENGINE DATA	COST (35) PROPELLER COST
ENGDT6 (70) ENGINE DATA	GEARBX (45) GEARBOX COST, WEIGHT
ENGDT7 (145) ENGINE DATA	WAIT (30) PROPELLER WEIGHT
ENGDTT (35) ENGINE DATA	
NACDG (35) NACELLE DRAG	PNOYS (50) CONTROLS PROP/ENGINE NOISE CALCULATION
	ZNENG (55) ENGINE NOISE CHARACTERISTICS
	ZNOISE (105) PROPELLER NOISE

FIGURE IV.1.1 PROPULSION SUBROUTINES

The engine sizing problem is iterative, because of the effect of nacelle geometry on total aircraft drag. The input flag KNAC accounts for nacelle drag by the following means:

KNAC = 0 Nacelle drag is included as an engine performance penalty. Nacelle size is a function of engine size and is computed during engine sizing. [1]

KNAC = 1 Nacelle drag is accounted for as an aerodynamic force. Nacelle size is a function of engine size and is computed during engine sizing

KNAC = 2 Same as KNAC = 1, but nacelle dimensions are input and remain fixed.

When KNAC = 0 or 1, the nacelle size is initially estimated as a function of aircraft gross weight since the engine size is unknown. The required engine size is then computed, and, based on this engine size, an improved estimate of the nacelle dimensions is made. The nacelle diameter is computed from the sea level statis airflow (WASLS), the fan face Mach number (SM1D, input), and the fan hub-to-tip ratio (HBTP, input) using one-dimensional isentropic compressible flow theory; the nacelle length is computed from the diameter and an input nacelle fineness ratio (XLQDE). Based on these dimensions the nacelle drag is recomputed, and the engine sizing process is repeated once.

When KNAC = 0, the nacelle drag is computed exactly as when KNAC = 1. Engine specific thrust and specific fuel consumption are adjusted for nacelle drag in subroutine NACDG.

The flight condition input flag for engine sizing (JENGSZ) can take on the following values:

---

[1] Applies to turbofan/turbojet configuration

JENGSZ	FLIGHT CONDITION
0	Size engine for cruise flight condition
1	Size engine for cruise and takeoff flight conditions
2	Size engine for cruise and takeoff and one-engine-out climb flight conditions
3	Size engine for cruise and one-engine-out climb flight conditions
4	Engine thrust is specified.

The engines are initially sized at the design cruise flight conditions except when the engine size is input (JENGSZ = 4). This means that, at cruise power setting, the engines must produce total thrust equal to the cruise drag of the aircraft. If a cruise climb margin is specified (RCCRU), the engines must also have enough excess cruise thrust to meet this margin.

The required engine size, expressed as sea level static airflow (WASLS) is computed by scaling the performance of the reference engine to match the required cruise thrust. Engine performance is scaled by assuming that at a given altitude, Mach number, and engine power setting the specific thrust (SFN = thrust per unit airflow) and percent corrected airflow (PCWAC = corrected airflow/WASLS) of the scaled engine are the same as for the reference engine. Thus, the sea level static airflow of the engine is computed by

$$\text{Cruise Airflow} = \text{required thrust/SFN}$$

$$\text{Corrected Cruise Airflow} = \left(\text{Cruise Airflow} \times \frac{\sqrt{\dfrac{\text{Total Temp}}{\text{SLS Temp}}}}{\dfrac{\text{Total Pressure}}{\text{SLS Pressure}}} \right)$$

$$\text{WASLS} = \text{Corrected Cruise Airflow/PCWAC}$$

When JENGSZ = 1 or 2, the take-off distance of the aircraft (with engines sized for cruise) is computed (ENGSZ calls PERFRM which calls TAKOFF) and compared with the input required distance (XTORQ), the required take-off distance may be for high altitude and for hot day conditions. If the computed distance exceeds the required distance, then the engines are resized by adjusting the airflow to meet this requirement.

Federal Air Regulations Parts 23 and 25 establish climb requirements. For example, FAR Part 25 requirements are summarized in Figure IV.1.2. When JENGSZ is input as 2 or 3, ENGSZ computes the climb performance of the aircraft in accordance with Part 23 or 25 and compares the computed performance with the required performance. If necessary, the engines are resized so that the aircraft meets the most critical requirement.

ENGSZ includes an option for sizing the engines for an input turning performance requirement. This option (JTRSZ = 1) must be used in conjunction with one of the engine sizing options described above (JENGSZ = 0-3; may not be used with JENGSZ = 4).

The user must specify the required turn load factor, altitude and Mach number (XLFTRN, HTURN, EMTURN - input). ENGSZ computes the thrust required to execute the turn and compares this thrust with that available from the engines at the desired power setting (engines as sized for cruise, takeoff, or climb). If insufficient thrust is available, engine thrust is set equal to that required, and a new sea level static airflow is determined. An additional iteration is performed to account for resized nacelles when nacelle size is a function of engine airflow (KNAC = 0, 1).

Turning performance may be limited by the maximum lift coefficient in the turn configuration. This limiting lift coefficient may be specified by the user (input as CLTLMT; default = 1.0). If the required lift coefficient in the turn exceeds the maximum turn lift coefficient, the turn load factor is automatically reduced to the value achievable by the aircraft at its limiting turn lift coefficient.

The simplest engine sizing option (JENGSZ = 4) is for the user to specify the rated sea-level static thrust (THIN, lbs.) of one engine. In this case engine sizing at cruise is bypassed. Engine-out climb performance is computed as when sizing for climb; however, if a climb deficiency is detected, the engines are not resized.

When the engine size is input, several additional inputs are required. The nacelle size must be specified (KNAC = 2, ELN and DBARN). In addition, the engine, nacelle, and pylon weights (WENG, WNAC, WPYLON) must be input if non-zero values are desired.

IV.1.1.1 Engine Performance at a Specified Flight Condition - Subroutine ENGINE. Subroutine ENGINE determines engine performance at a specified altitude and flight Mach number. Engine performance is described by thrust, airflow, fuel flow, specific thrust, per cent corrected airflow, and thrust specific fuel consumption. Performance data for different engine cycles are contained in subroutines ENGDT1-7, and ENGDTT as functions of altitude, Mach number, and power setting. Either power setting or required thrust is specified, and the other is to be found.

The performance of a particular engine may be scaled up or down by assuming that at a given Mach number, altitude, and engine power setting, the specific thrust (SFN = lbs. thrust/lbs./sec airflow), the specific fuel

CONFIGURATION	IRQ	ALT. ABOVE AIRPORT, FT	CLIMB VELOCITY (V_C) (KNOTS)	REQUIRED CLIMB GRADIENT	SOURCE
TAKEOFF FLAPS. LANDING GEAR DOWN ONE ENGINE OUT (FIRST SEGMENT)	1	0	$V_C = V_{LOF}$ $V_{LOF} \leq 1.2\ V_{STALL}$ @ T.O.	POSITIVE (RC $\geq$ 1 FT/S)	FAR 25.121(a) 2 engine
TAKEOFF FLAPS LANDING GEAR UP ONE ENGINE OUT (SECOND SEGMENT	2	250	$V_C = 1.2\ V_{STALL}$ @ T.O.	2.4% (RC $\geq V_{CLIMB}$*.024 F/S)	FAR 25.121(b) 2 engine
CLEAN CONFIGU- RATION ONE ENGINE OUT (FINAL TAKEOFF)	3	1500	$V_C \geq 1.25\ V_{STALL_{CLEAN}}$	1.2% (RC $\geq V_{CLIMB}$*.021 F/S)	FAR 25.121(c) 2 engine
APPROACH CONFIGU- RATION ONE ENGINE OUT	4	0	$V_C \leq 1.5*V_{STALL}$ @ APP $V_C \leq 1.1*V_{STALL}$ @ LAND	2.1% (RC $\geq V_{CLIMB}$*.021 F/S)	FAR 25.121(d) 2 engine
LANDING CONFIGU- RATION ALL ENGINES	5	0	$1.3 * V_{STALL}$ @ LAND	3.2% (RC $\geq V_{CLIMB}$*.032 F/S)	FAR 25.119 2 engine

FIGURE IV.1.2 ENGSZ: FIRST AND SECOND SEGMENT CLIMB REQUIREMENTS (FAR PART 25) consumption (SFC = lbs. of fuel per hour per pound of thrust), and the per cent corrected airflow (corrected airflow divided by sea level static airflow) of the scaled engine are the same as for the unscaled engine. Once the sea level static airflow (WASLS) is established by subroutine ENGSZ, the scaled engine performance at the specified operating point follows immediately:

Airflow:	W_G = WASLS x PCWAC x $\delta/\sqrt{\theta}$
Thrust	F_N = SFN x W_G
Fuel Flow:	W_F = SFC/F_N

where

δ = total pressure/SLS pressure

θ = total temperature/SLS temperature

The different functions of ENGINE are controlled by the indicator KENG:

<u>KENG = 1</u> (Variable corrected rotor speed)

This option is used when the required thrust is known, for example during cruise at a specified altitude and Mach number. The engine power setting is found at which engine thrust is equal to required thrust. The fuel flow at this power setting is used in the range calculation. Engine data are <u>not</u> scaled.

<u>KENG = 2</u> (Idle power setting)

Engine performance at idle is used during the taxi segment and during the landing calculation (only if the engines have already been sized)

<u>KENG = 3</u> (Maximum cruise corrected rotor speed)

This option is used during engine sizing at cruise and during performance calculations at maximum cruise power. Engine power setting is known, and engine performance is determined. If the engines have already been sized, engine performance is computed from WASLS, PCWAC, SFN, and SFC. During engine sizing, specific engine performance (PCWAC, SFC) is used the required cruise thrust to compute engine size (see Section IV.1).

KENG = 4 (Variable Corrected Rotor Speed

This option is the same as KENG = 1, except that engine data are scaled using WASLS, PCWAC, SFN, and SFC.

KENG = 5 (Maximum Corrected Rotor Speed)

ENGINE determines the scaled engine performance available at the operating flight condition and maximum engine power setting. This option is used during take-off and climb.

KENG = 6 and 7 (Maximum Continuous Power Setting)

KENG = 7 (Maximum Climb Power Setting)

KENG is automatically set according to the type of performance calculation whenever ENGINE is called. Take-off, climb, acceleration, and turn performance are normally computed at maximum corrected rotor speed with KENG = 5. Cruise performance at normal rated power is computed at maximum cruise power (KENG = 3). Cruise performance at a specified Mach number is computed with KENG = 4.

Takeoff, climb, acceleration or turn performance will be computed at maximum continuous (KENG = 6) or maximum climb (KENG = 7) power settings rather than maximum power if the variables KODETO, KODECL, KODEAC, and KODETR are input as 6 or 7 (default values for these variables are 5).

For all of these options, it is assumed that the following normalized engine parameters are the same for the scaled engine as for the model engine:

1. Percent corrected airflow, PCWAC
2. Specific thrust, SFN
3. Specific fuel consumption, SFC

The two additional operational parameters needed are the ratios of total pressure and total temperature to sea level static values of these parameters, in terms of which the "corrected" values of thrust, airflow, and fuel flow can be found.

Other input parameters included in the subroutine call statement are

FN = engine thrust, lb (if power setting is being computed)

SFC = engine specific fuel consumption, lb per sec per lb

FAR = fuel-to-air ratio

PO = ambient static pressure, lb per sq ft

TO = ambient static temperature, deg R

SMN = engine Mach number

HN = altitude, ft

Primary output quantities of the routine are

FN = engine thrust, lb (if power setting is known)

WF = fuel flow, lb per hr

IV.1.1.2 Engine Data Subroutines. Turbofan/turbojet engine performance data is available in the following eight subroutines:

SUBROUTINE	ENGINE	IENGSC
ENGDT1	GE CJ610-6 (Turbojet)	1
ENGDT2	Garrett TFE 731-2 (Turbofan)	2
ENGDT3	UACL JT15D-1 (Turbofan)	3
ENGDT4	Lycoming ALF-502 (Turbofan)	4
ENGDT5	GE CF 34 (Turbofan)	5
ENGDT6	GE TF 34 (Turbofan)	6
ENGDT7	Conceptual GE T700/F1 QCGAT	7
ENGDTT	Tabular input engine data	≤ 0

The appropriate engine cycle is selected by the value of IENGSC which is read from the data deck title card (cols. 75-76).

Each engine data subroutine contains tabulated performance data for a specific engine cycle. For ENGDT1-7 these data consist of corrected thrust, corrected airflow, and corrected fuel flow tabulated as functions of engine power setting and flight Mach number. These relationships are illustrated schematically in Figure IV.1.3. The effect of altitude is contained implicitly in the total temperature and total pressure ratios (θ and δ).

These normalized or specific quantities, used to scale engine performance, are computed each time ENGDT is called: per cent corrected airflow (PCWAC), specific thrust (SFN), and specific fuel consumption (SFC).

Engine power setting is established according to the value of KENG, which is set in subroutine ENGINE:

KENG =	5	maximum power
	1, 4	variable power
	3	maximum cruise power
	2	idle power
	6	maximum continuous power
	7	maximum climb power

Typically, engine power setting is expressed as either the ratio of turbine inlet temperature to engine face total temperature (T5/T2) or per cent corrected rotor speed ($N/\sqrt{\theta}/N_{MAX}$). Each engine cycle does not necessarily possess the complete range of power settings indicated by KENG. For example, maximum continuous power may be identical to maximum cruise power, etc.

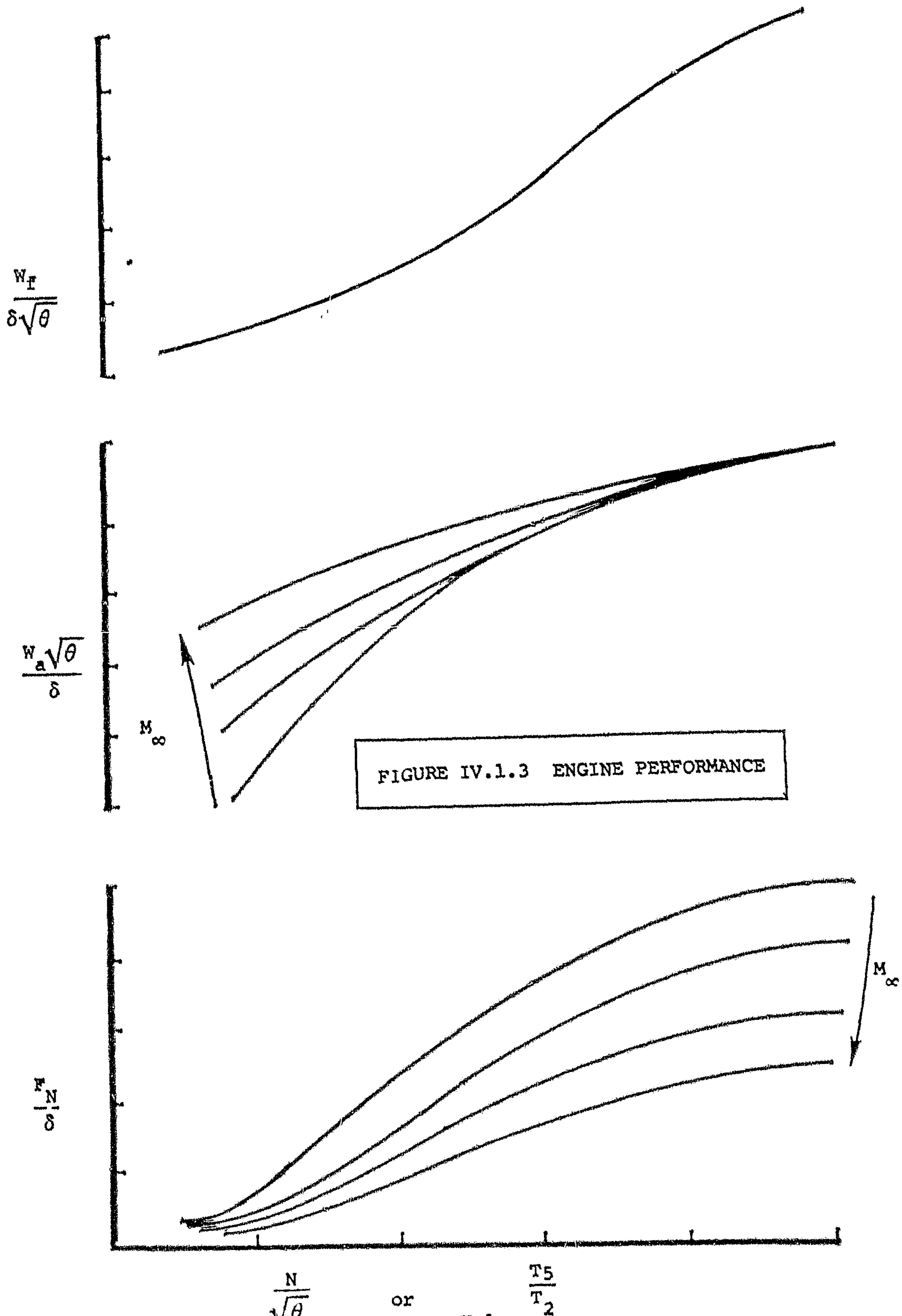

FIGURE IV.1.3 ENGINE PERFORMANCE

ENGDTT differs from ENGDT1-7 in that the engine corrected performance data are tabulated as <u>explicit</u> functions of altitude as well as power setting and Mach number. In addition, these tables must be read from cards at the beginning of each run (see input deck description). These engine data are read, stored, and interpolated with the aid of several special utility subroutines and functions (MAPS, STORE3, TTABX, TABX, DTABX, BISC).

Engine idle performance (KENG = 2) is determined slightly differently for each engine cycle. In the simplest cases, numerical values are assumed for idle corrected thrust, corrected fuel flow, and corrected airflow. Two engine cycles (ENGDT2, 3) express corrected engine-idle performance as explicit functions of altitude.

All of these subroutines have the same list of 13 arguments, which effectively specify all aspects of engine performance. These arguments are

FN = engine thrust, lb

WF = fuel flow, lb per hr

WA = airflow, lb per hr

PCWAC = percent corrected airflow

= corrected airflow/SLS airflow

SFC = specific fuel consumption, lb per hr per lb thrust

SFN = specific thrust, lb per lb per hr airflow

FAR = fuel/air ratio, lb per sec of fuel per lb per hr of air

P2 = static pressure at inlet, lb per sq ft

T2 = static temperature at inlet, deg R

HN = altitude, ft

SM = Flight Mach number

FTHROT = per cent maximum throttle setting

KENG = engine power setting indicator (0-7)

The output quantities are the first seven of these parameters (input being the last six), and they are determined by interpolation in the numerical performance tables which make up the major part of the ENGDAT1-7 subroutines.

IV.1.1.3 Nacelle Losses Computation, Subroutine NACDG. This subroutine corrects the engine specific fuel consumption and specific thrust to include losses due to nacelle drag. It is called by ENGINE when KNAC = 0, and the subroutine subtracts nacelle drag from gross engine thrust to provide a net engine thrust. The drag coefficient is approximated by using flat-plate turbulent boundary layer theory, and this depends on the cylindrical nacelle dimensions and the Reynolds number of the nacelle.

The input arguments of the subroutine relate to the flight conditions and the aircraft geometry, as needed for drag coefficient computation. These include static pressure PO, Mach number SMN and wing area SWING. The output quantities are the corrected specific fuel consumption and specific thrust (SFC, SFN) and the total airflow, W_A.

IV.1.2 Propeller Propulsion Subroutines

The propeller propulsion subroutines in GASP are used to simulate the performance of reciprocating, rotary combustion, and turboprop propulsion systems. Several of these subroutines replace equivalent turbofan engine subroutines and thus have the same names.

Subroutine ENGSZ, like its turbofan equivalent, controls several engine sizing options. It determines the engine size necessary to allow the aircraft to meet a set of performance requirements. The engine performance subroutine, ENGINE, is called during engine sizing and each time propulsion system performance is required.It relates the performance of the propeller, controlled by subroutine ENGDAT, to the performance of the powerplant, computed in subroutine PWRPLT for rotary combusion and reciprocating engines and in TURBEG for turboprop engines.

Reciprocating and rotary combustion engine performance (subroutine PWRPLT) is based on generalized, non-dimensional relationships between power, engine speed, and altitude. Both normally aspirated and turbo-charged engines may be simulated.

Turboprop engine performance is based on tabulated data for a specific engine cycle. Currently, data for the Garrett TPE 331-1 turboprop are included in the program (subroutine TURBEG). The performance of the baseline engine may be scaled up or down.

Propeller performance is computed as a function of the propeller geometry and operating condition using generalized performance relationships. These data are contained in subroutine PERFRM, which is called by ENGDAT whenever propeller performance is to be computed.

IV.1.2.1 Propeller Subroutine, ENGSZ. The propeller subroutine ENGSZ determines the engine size necessary to meet cruise, and, optionally, take-off and/or climb requirements. Engine size is expressed as maximum sea level horsepower for reciprocating, turboprop, and rotary combustion engines.

The engine size may be input directly as HPMSLS by also inputting KODECR = 7. In this case, the engine sizing process is bypassed. For fixed pitch propeller configurations, propeller blade angle (BLANG) must also be input when the engine size is input. The input flag JENGSZ determines the sizing options, as follows:

JENGSZ = 0: size at cruise only

1: size at cruise and takeoff

2: size at cruise, takeoff and climb

3: size at cruise and climb

In all cases, the engines are sized to provide the required cruise thrust at an input flight condition and engine operating point. In the last three cases, the engine size may be increased so that the takeoff and climb performance requirements are met.

The cruise condition is specified by altitude, Mach number, cruise weight, required cruise rate of climb and engine operating point. When all of these parameters are specified, the thrust required for a given rate of climb is easily expressed as a function of cruise drag, weight,velocity, and rate of climb. Engine sizing at cruise involves computing the horsepower necessary to produce the required thrust at the design cruise condition. Since this cruise power is a specified fraction of maximum sea level power, the rated power of the engine may be computed.

As was discussed in Section IV.1.1 there exist thr nacelle drag accounting options ; however, only two are available for propeller power configurations.

KNAC = 1 Nacelle drag is computed in ENGSZ as engine size is determined. Nacelle size is a function of engine power.

KNAC = 2 Nacelle drag is computed from input nacelle dimensions in AERO. This option should be used to zero out nacelle drag for single engine nose mounted engines or other configurations with buried engines.

In any case, nacelle drag is found as an explicit function of nacelle Reynolds number and wetted area, and the wetted area and Reynolds number are both numerical functions of aircraft geometry.

The engines may be resized to enable the aircraft to meet an input take-off field length requirement (JENGSZ = 1 or 2). This requirement may include high altitude and/or hot day conditions. The take-off performance of the aircraft with engines sized for cruise is computed (calls to subroutines PERFRM) and TAKEOFF) and if the computed take-off distance exceeds the required distance, ENGSZ iterates on engine power until the take-off requirement is met.

When JENGSZ = 2 or 3, the program compares the aircraft's climb performance with the requirements established in Federal Aviation Requirements, Part 23 or 25 (shown in Figure IV.1.3). If one or more of these requirements is not met, the engine size is increased to satisfy the most critical requirement.

Propeller diameter is an input variable; however, if the engines are resized for take-off and/or climb, propeller diameter may or may not be changed according to the input variable JSIZE:

JSIZE = 1 Increase power but leave propeller diameter constant

= 2 Increase both power and diameter but keep propeller disk loading (power/area) constant

When the engines are sized such that all take-off and climb requirements are met, additional engine resizing may be needed if KNAC = 1. In this case the engine resizing is repeated, based on the new estimate of nacelle size. And, if engine is resized only at climb, with KNAC = 1, the climb performance must be recomputed using the new estimate of nacelle drag. Again, in this case, engine power may be increased until desired performance is attained.

Engine sizing for fixed pitch propeller configurations is handled somewhat differently than for constant speed propeller configurations. The engine is initially sized at cruise just as for constant speed configurations. The propeller blade angle computed at cruise is held fixed for subsequent performance calculations. Thus, initial sizing at cruise establishes both the engine size and the propeller blade angle.

If the climb performance of a fixed pitch propeller aircraft with the blade angle set for cruise does not meet all the climb requirements (JENGSZ = 2 or 3), then the blade angle is decreased by two degree increments, and the climb performance is recomputed. The largest blade angle for which all requirements are met is fixed as the new blade angle. If blade angle reductions alone fail to sufficiently improve climb performance, then engine power is increased and the propeller blade angle is set for the critical climb requirement.

IV.1.2.2 Power Plant/Propeller Matching, Subroutine ENGINE. The most important function of subroutine ENGINE is to relate the performance of the powerplant (piston engine, rotary combustion engine, or gas turbine engine) to the performance of the propeller (or other propulsor, such as a Q-fan). ENGINE is called during engine sizing and during performance calculations when either propeller thrust or engine power is known, and the other is to be determined.

Engine deals with several types of propulsion performance problems. The flag KENG which is passed to ENGINE through its argument list is used to specify the type of computation required. The indicator KODE is set in ENGINE according to the value of KENG and further specifies the type of computation. The types of engine performance calculations are summarized below:

KENG = 3 (KODE = 1, 2, 3, or 4)

This option is used during engine sizing at cruise when the required propulsive thrust is known, and the required engine size is computed. Normally, the engine cruise operating point (percent power and per cent RPM) is specified (KODE = 4). Options exist for adjusting propeller diameter (KODE = 1 or 2) or the propeller cruise RPM (KODE = 3) to maximize propeller efficiency at the design cruise flight condition. The value of KODE may be specified by inputting the appropriate value for KODECR.

KENG = 1 or 4 (KODE = 5 or 6)

This option is used during cruise performance calculations when the cruise Mach number and altitude are specified. The engine and propeller characteristics are fixed, and the required propulsive thrust is known. ENGINE finds the power setting required to drive the propeller and the corresponding fuel consumption. Propeller RPM is either specified at the design cruise value (KODE = 6), or ENGINE will select the RPM which maximizes propeller efficiency (KODE = 5). The value of KODE may be selected by inputting the appropriate value for KODETH.

KENG = 0 or 5 (KODE = 7)

This option is used when the engine size, power setting, RPM, and aircraft flight speed are known and the resultant thrust and fuel consumption are computed. This situation corresponds to aircraft equipped with variable pitch propellers during take-off, climb, acceleration, and cruise at a specified power setting.

(KODE = 8)

This option is used to predict the performance of aircraft equipped with fixed pitch propellers during full throttle operation at a specified airspeed (take-off, climb, acceleration). ENGINE finds the engine and propeller RPM at which full throttle power available equals the power absorbed by the propeller. Having found the equilibrium RPM, ENGINE finds the corresponding propeller thrust and engine power and fuel consumption.

ENGINE finds propeller performance by calling subroutine ENGDAT. Powerplant performance is found from subroutine PWRPLT for piston and rotary combustion engines and TURBEG for turboprop engines.

One important function of subroutine ENGINE is to insure that the operating conditions of the propeller and powerplant are compatible. Specifically the power required to turn a propeller at some RPM and flight condition must not exceed the maximum power available from the engine at that RPM and flight condition. If power required exceeds power available at the specified RPM, ENGINE seeks some other engine speed where power available is sufficient to drive the propeller.

IV.1.2.3 <u>Power and Fuel Flow Computations, Subroutine PWRPLT</u>. This subroutine computes the power and fuel flow of an internal combustion piston engine. It can be used to determine the engine size required to meet an aircraft performance requirement, or to predict the engine performance at a given operating point. It uses generalized dimensionless relationships between power and rpm, and between corrected power and altitude so as to predict the full throttle power of an engine for any realistic combination of rpm and altitude.

When operating losses are ignored, the power available from a piston engine is proportional to the product of displacement, rpm, and brake mean effective pressure or throttle setting. The losses increase with the rpm, so the power of a specific engine varies as shown in Figure IV.1.4. The non-dimensional relationship between power and rpm contained in PWRPLT is illustrated in Figure IV.1.5. Also illustrated is the relationship between corrected power and altitude.

Super charged (and turbo charged) engines maintain their rated sea level power up to some critical altitude above which maximum power decreases. Maximum power at altitudes above the critical altitude is related to maximum sea level power by

$$\mathrm{HPM} = \frac{(\mathrm{SIGMA} - .117)}{(\mathrm{SIGCRT} - .117)} \times \mathrm{HPMSLS}$$

where

$$\mathrm{SIGMA} = \frac{\text{air density at altitude}}{\text{air density at sea level}}$$

$$\mathrm{SIGCRT} = \frac{\text{air density at critical altitude}}{\text{air density at sea level}}$$

as discussed in <u>Principles of Aerodynamics</u>, authored by Dwinnel (McGraw-Hill, 1949).

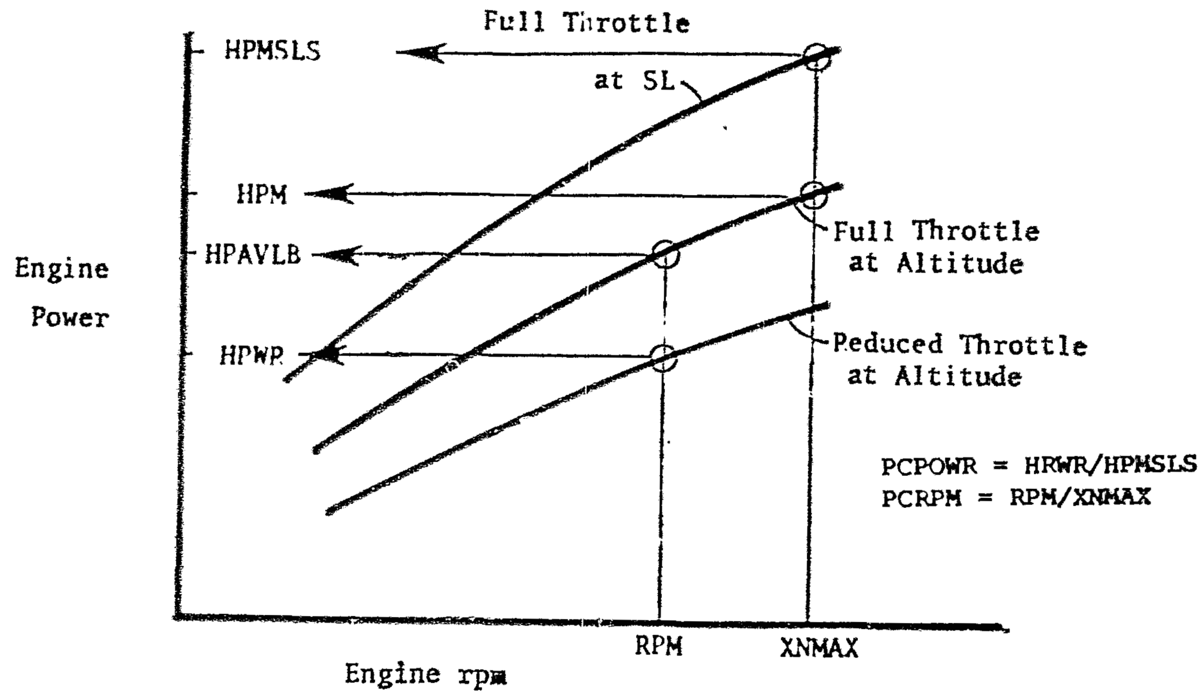

FIGURE IV.1.4 ENGINE POWER VARIATION WITH RPM AND THROTTLE

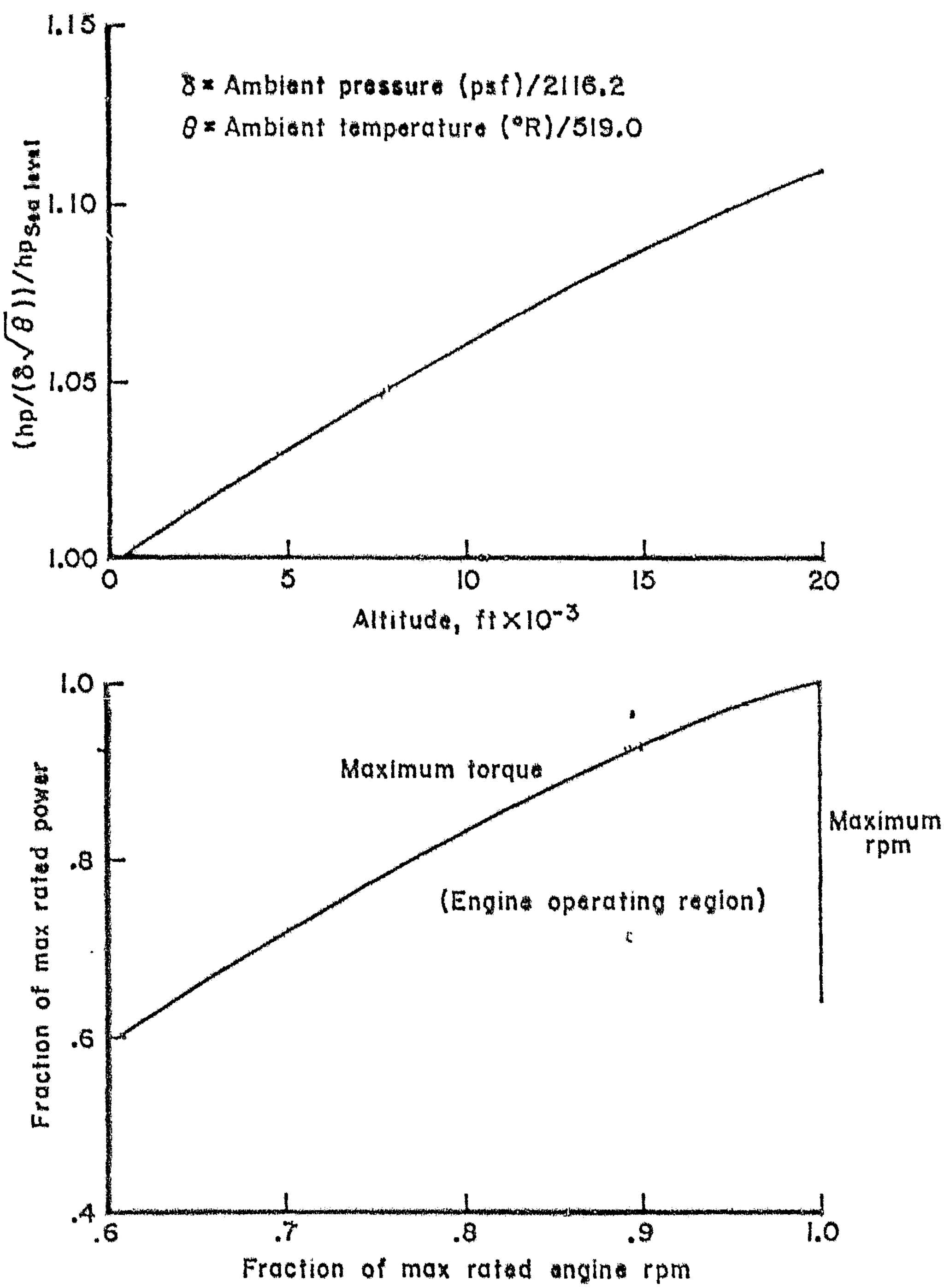

FIGURE IV.1.5 PART POWER AND ALTITUDE PERFORMANCE OF AIRCRAFT PISTON ENGINES

The operating point of a particular engine (fixed displacement) is specified by the engine RPM and engine manifold pressure. In aircraft equipped with constant speed propellers, the pilot controls manifold pressure with the throttle; he controls engine speed by setting the propeller governor which adjusts the propeller blade angle such that the propeller absorbs the power developed by the engine at the desired throttle setting and engine RPM. Generally, either the engine operating point (power and RPM) or the aircraft flight condition (altitude and airspeed) is known and the other must be determined.

The analysis of engines with fixed pitch propellers is somewhat more complicated. In this case the only power control is the throttle position. For a given throttle position and aircraft airspeed and altitude, the engine operates at that RPM at which power absorbed by the propeller equals the power produced at the crankshaft. The pilot may indirectly control RPM by adjusting the throttle position and aircraft airspeed (trim control) such that, at the desired engine RPM, the power developed by the engine is absorbed by the propeller.

During engine sizing at cruise, the rated sea level horsepower of the engine is computed from the power required to drive the propeller (HPWR) and the input cruise engine power setting (PCPOWR = power at cruise/SLS power):

$$HPMSLS = HPWR/PCPOWR$$

Reciprocating engine fuel consumption is expressed in PWRPLT as an empirical function of engine displacement and engine power setting. These relationships are illustrated for naturally aspirated and turbocharged engines in Figures IV.1.6 and IV.1.7, respectively. Fuel consumption at power settings less than

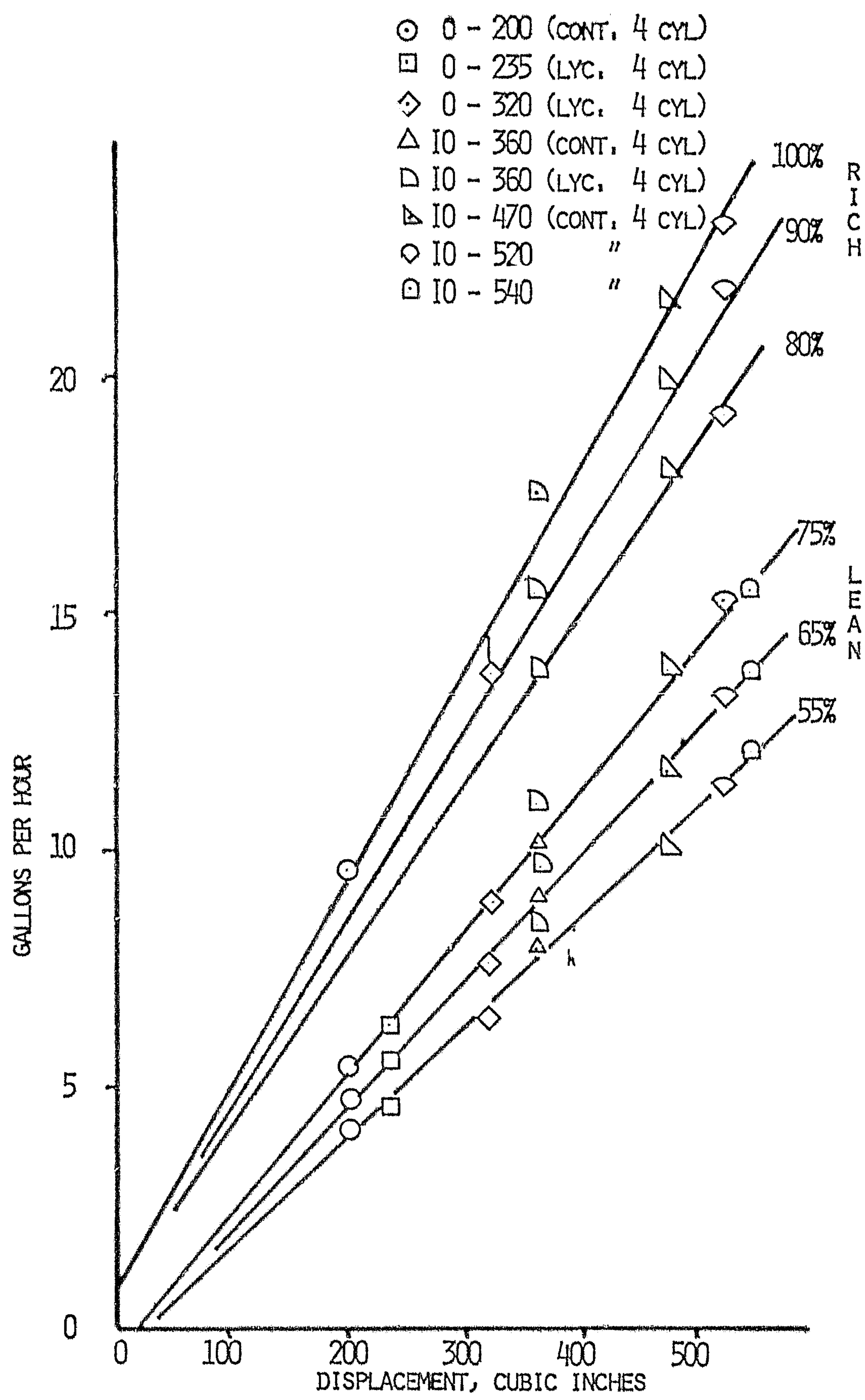

FIGURE IV.I.6 - FUEL FLOW NATURALLY ASPIRATED - DIRECT DRIVE

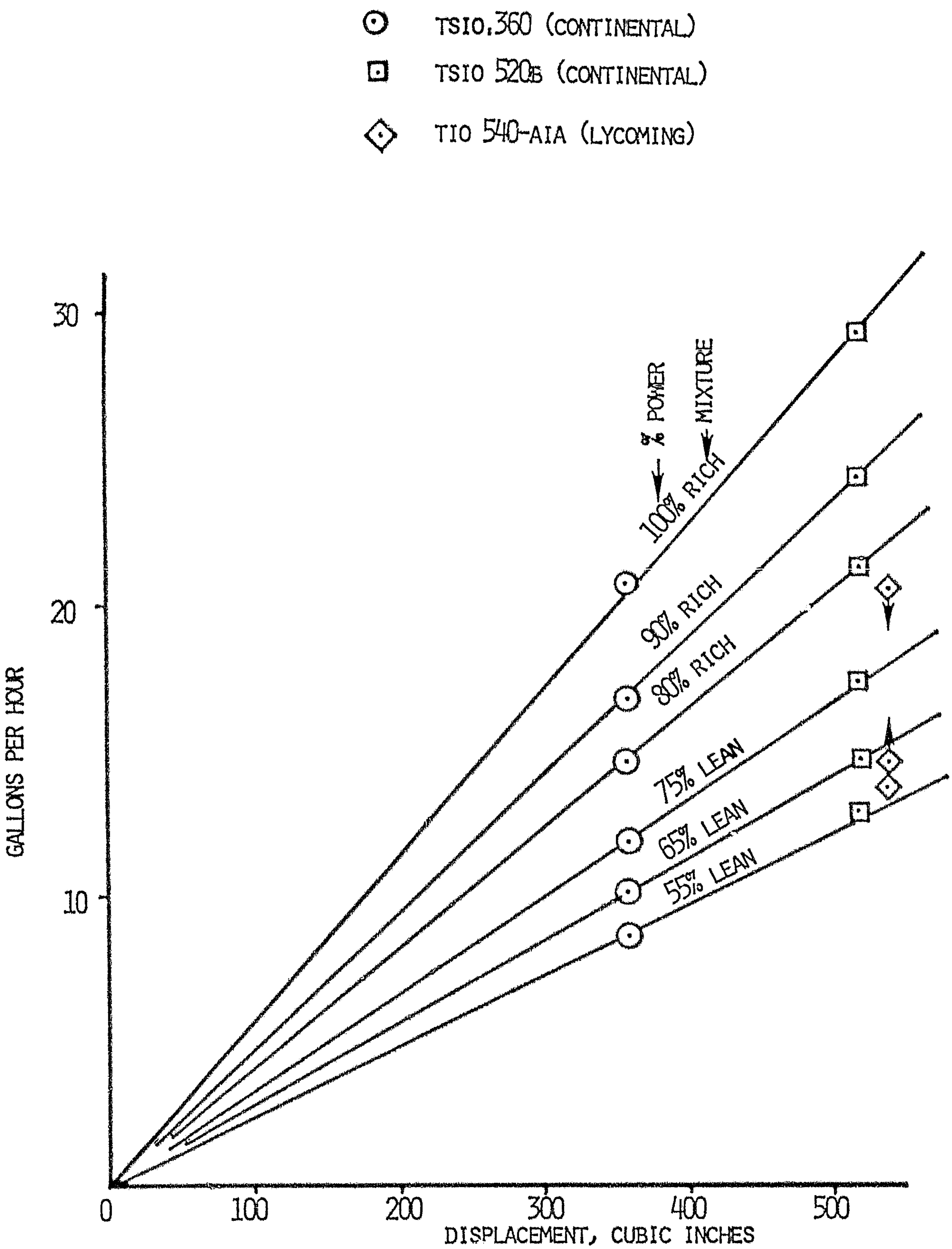

FIGURE IV.I.7 - FUEL CONSUMPTION, TURBO-CHARGED DIRECT DRIVE or equal to 78 per cent of maximum sea level power is computed assuming a lean fuel mixture.

The input option KODE (= 1 to 9) specifies whether the engine size or the engine performance is found, and the other arguments in the call statement are

HPM = maximum power available at altitude (output)

HPMSLS = maximum sea level power at full throttle, maximum rpm (output)

HPWR = actual power at operating throttle and rpm (input or output)

HPAVLB = maximum full throttle power at altitude and at operating rpm (output)

PCPOWR = per cent rated power (input or output)

PCRPM = per cent maximum rpm (input)

DELTA = operating static pressure ratio (input)

RTHET = square root of operating static temperature ratio (input)

H = altitude, ft (input)

KSPCHG = supercharger flag (input)

BSFC = brake specific fuel consumption, lb per hr per hp (output)

The first six of these quantities are illustrated in Figure IV.1.4.

IV.1.2.4 Turboprop Engine Performance, Subroutine TURBEG. Nearly half of this 270 card subroutine is numerical data, descriptive of the AIRESEARCH TPE331-1 turboprop engine. The program is used to scale this engine at a given flight condition and operating point, or to compute the performance of a given size engine at a specified operating point. The performance parameters of interest are shaft power, fuel flow and jet thrust.

The engine operating point and the flight condition together define the engine performance. The flight condition is specified by the first three call parameters:

PO = static pressure, lb per sq ft (input)

TO = static temperature, deg R (input)

SMN = Mach number (input)

Engine performance is measured by the next several call variables, i.e., HPWR, HPAVLB, HPM and HPMSLS are as defined in the previous section while:

PCNCR = per cent corrected maximum rotor speed (input or output)

PCN = per cent maximum rotor speed (output)

T4SET = turbine inlet temperature, deg R (input)

WF = fuel flow, lb per hr (output)

FN = jet thrust, lb (output)

The remaining call parameters are

XNMAX = maximum engine RPM (input)

GR = gear ratio; maximum propeller rpm/maximum engine rpm (output)

MODEP = 0, cruise operation

= 1, takeoff operation (input)

KODE = 1 to 7, engine sizing options (input)

The performance of the reference engine is scaled by straightforward means according to the value input for KODE: i.e.,

KODE = 1 engine is being sized at a given flight condition, PCNCR is input and T4 is either input or a function of PCNCR

KODE = 2 or 7 engine size fixed, PCNCR is input, T4 is input, or T4/T2 is a function of PCNCR

3 or 4 same as KODE = 1, except required power is a fraction of the power sized at input value of PCNCR

5 or 6 engine size fixed, PCNCR is input, determine T4/T2 so as to balance required and available power

The corrected performance figures of the TPE 331-1 engine, at three flight Mach numbers (0., .25 and .50), are tabulated in TURBEG as functions of the engine operating point. The actual performance, for arbitrary altitude and Mach number, is found by interpolation or extrapolation of the tabulated data, and by applying the correction factors.

A major portion of the subroutine is concerned with the scaling of several performance parameters from the reference engine performance data. The performance is specified by the horsepower, fuel flow, airflow and jet thrust, all of which vary linearly with engine size. Such operating variables as turbine inlet temperature and corrected rotor speed may be specified independently as constraints on the scaled engine.

The performance of the TPE 331 engine is scaled by the ratio of the sea level static horsepower of the scaled engine (HPMSLS - determined during engine sizing or input) to the sea level static horsepower of the TPE 331 (HPSLRF):

horsepower: $$HPWR_{SCALED} = HPWR_{TPE\ 331} \times \left(\frac{HPMSLS}{HPSLRF}\right)$$

jet thrust: $$FN_{SCALED} = FN_{TPE\ 331} \times \left(\frac{HPMSLS}{HPSLRF}\right)$$

fuel flow: $$WF_{SCALED} = WF_{TPE\ 331} \times \left(\frac{HPMSLS}{HPSLRF}\right)$$

The scaled airflow is used to compute the maximum engine speed of the scaled engine from which the scaled engine's gear ratio is determined:

engine speed: $$RPM_{MAX_{SCALED}} = RPM_{MAX_{TPE331}} \times \frac{WA_{TPE331}}{WA_{SCALED}}$$

gear ratio: $$GR_{SCALED} = GR_{TPE331} \times \frac{RPM_{MAX_{TPE331}}}{RPM_{MAX_{SCALED}}}$$

Note that maximum propeller shaft speed remains unchanged as the engine is scaled.

IV.1.3 Propeller Characteristics, Subroutine ENGDAT

This subroutine controls the calling of the propeller related routines and deals with four aspects of the propeller requirements:

1. Performance option - finds power/thrust/blade angle relationship at given flight condition and propeller rpm
2. Cost option - finds cost of propeller and gearbox
3. Weight option - finds weight of propeller and gearbox
4. Noise option - finds noise of propeller and gearbox

The indicator KODE specifies which of the four options is desired, according to the value given to this argument:

KODE = 1 to 10: performance option
11 to 20: cost option
21 to 30: weight option
31 to 40: noise option

Other input-output arguments of the program are, in order:

GR = gear ratio, prop rpm/engine rpm (input)

DROT = propeller diameter, ft (input)

THRUST= thrust, lb (innut/output)

SHP = shaft horsepower (input/output)

EFFP = propeller efficiency (output)

VKTS = airplane velocity, kts (input)

RORO = ratio of air density to sea level density (input)

IERROR= error indicator (output)

ENP = number of engines (input)

PO,TO = static pressure and temperature at altitude (input)

AFX = activity factor (input)

BLX = number of blades (input)

The propeller performance option is the most complex. Whenever propeller performance is computed, the propeller geometry, RPM, and aircraft airspeed are known. Together they define the advance ratio J:

$$J = \frac{101.4 \ \text{x Airspeed (kts)}}{\text{RPM x Diameter (ft)}}$$

For a given advance ratio, the propeller performance problem can take one of three forms:

1. knowing thrust and advance ratio, find blade angle and power
2. knowing power and advance ratio, find blade angle and thrust
3. knowing blade angle and advance ratio, find thrust and power

The first problem is encountered by a constant speed (variable blade angle) propeller during cruise at a specified altitude and Mach number. The second problem occurs with a constant speed propeller during take-off, climb, and cruise at a specified power setting. The final case is used to compute the performance of a fixed pitch propeller during all flight segments. In all three cases ENGDAT calls subroutine PERFM which consists of generalized propeller performance tables.

IV.1.3.1 Subroutine PERFM. PERFM is the propeller performance subroutine based on Hamilton Standard methods described in NASA CR-2066. For a given propeller geometry it relates power and thrust coefficients, advance ratio, and blade angle. Correction factors are applied to account for differences in number of blades per propeller, activity factor per blade, and blade integrated design lift coefficient.

Subroutine PERFM is nearly 500 cards in length, but about half of the program is numerical data, descriptive of propeller relationships, including blade geometry, propeller aerodynamics, power coefficients, etc. The remainder is concerned largely with the interpolation of this input data for the particular propeller input characteristics. Use is made of the utility subroutines BIQUAD and UNINT, for biquadratic interpolation of Y(X), and for uniform four-point interpolation. PERFM is called by the propeller ENGDAT. The input parameters to subroutine PERFM are

IW	= 1, propeller power coefficient input
	= 2, propeller thrust coefficient input
	= 3, reverse thrust being calculated
	= 4, propeller blade angle input
ZJI	= propeller advance ratio
AFT	= activity factor per blade
BLADT	= number of blades

CLI = propeller blade integrated design coefficient

ZMS(1) = forward Mach number

ZMS(2) = tip Mach number

CP if IW = 1, power coefficient

CT if IW = 2, thrust coefficient

BLLLL if IW=4,blade angle

Output parameters from subroutine PERFM are

BLLLL and CT if IW = 1

BLLLL and CP if IW = 2

CT and CP if IW = 4

ASTERK = error flag if there is problem calculating propeller performance

XFT = compressibility correction factor

There are several numerical tests in the code related to being within the limits of the tabular data; i.e., if the error flag LIMIT is returned as 1 by either BIQUAD and UNINT, the data is outside the lower end of the tabular data. If LIMIT returned as 2, the data is outside the high end of the tabular data. An error message indicates in what table the problem occurs.

IV.1.3.2 Propeller Costs, Subroutine COST. This subroutine estimates propeller costs according to 1970 or 1980 manufacturing technologies and is called by the propeller ENGDAT. The following parameters are the input:

WTCON = type of propeller: = 1, fixed pitch propeller
= 2, constant speed propeller
= 3, constant speed, full feathering propeller

= 4, constant speed, full feathering, deicing propeller

= 5, constant speed, full feathering, deicing, reversing propeller

BLADT = number of blades

CLF1 = same as XCLF1

CLF = same as XCLF

CK70 = same as XCK70

CK80 = same as XCK80

CAMT = number of propellers produced (optional)

WT70 = propeller weight, 1970 technology, lb

WT80 = propeller weight, 1980 technology, lb

IENT = 1, initialization for propeller cost factors

= 2, computes propeller cost

The output quantities are found as numerical functions of these:

CQUAN(1) = number of propellers produced, 1970 technology default is a function of propeller type or can be input as CAMT

CQUAN(2) = number of propellers produced, 1980 technology default is a function of propeller type or can be input as CAMT

COST70 = propeller cost, 1970 technology

COST80 = propeller cost, 1980 technology

CCLF1 = learning curve factor - default function of propeller type or can be input as XCLF1

CCLF = learning curve factor - default function of propeller type or can be input as XCLF

Formulae used are

COST70 or COST80 = C = ZF $(3B^{0.75} + E)$

Default value of CCK70 or CCK80 = C_1 = $F(3B^{0.75} + E)$

where

COST70 or COST80 = C = Average O.E.M. propeller cost for a number of units/year, \$/lb

CCK70 or CCK80 = C_1 = single unit O.E.M. propeller cost, \$/lb.

Z = LF/LF_1

CCLF = LF = learning curve factor for a number of units/year (default = 1.02)

CCLF1 = LF_1 = learning curve factor for a single unit (default = 3.2178)

BLADT = B = number of blades

F = single unit cost factor

E = empirical factor

(NOTE: reference Figure IV.1.8 for LF and LF_1 values based on an 89 per cent slope learning curve.)

Constants used in these equations are

WTCON or NTYP	1970 CQUAN(1, WTCON)			1980 CQUAN(2, WTCON)		
	F	E	Quantity	F	E	Quantity
1	3.5	1.0	1910	3.5	1.0	2230
2	3.7	1.5	2810	3.7	1.5	5470
3	3.2	3.5	1030	3.2	3.5	1990
4	2.6	3.5	295	3.5	3.5	680
5	2.0	3.5	65	3.4	3.5	368

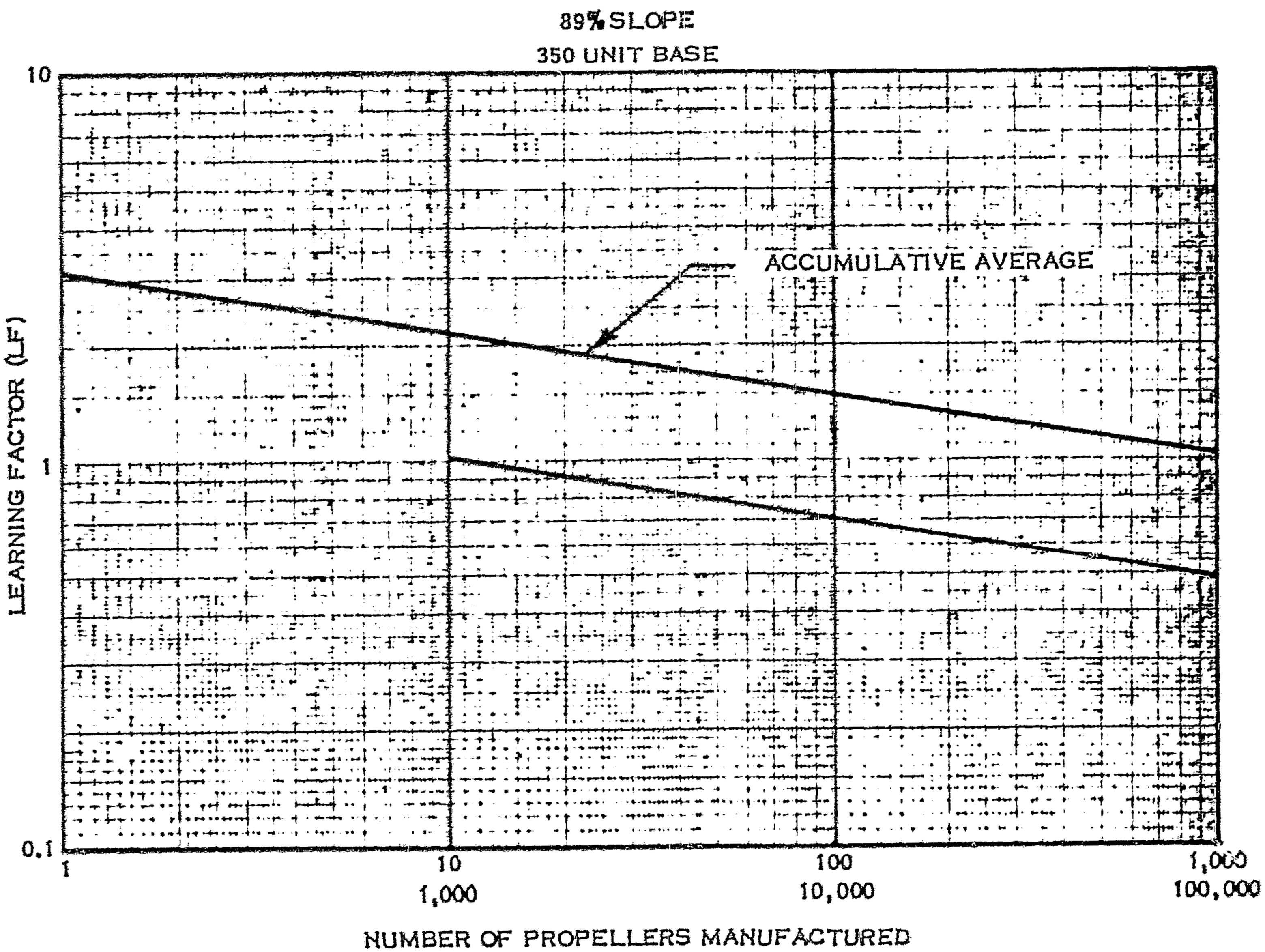

FIGURE IV.I.8 - LEARNING CURVE FOR GENERAL AVIATION PROPELLERS

IV.1.3.3 Gearbox Weight, Cost and Noise Characteristics, Subroutine GEARBX. The gearbox weight, cost and noise can all be found by this subroutine based on the 1973 Hamilton-Standard study, NASA CR-114665, "Q-FAN for General Aviation." The last of the input arguments is the flag MODE, which takes the values 1, 2, or 3, respectively, according to whether weight, cost or noise is to be computed. Other input parameters are

XNMAX = maximum engine rpm

PCRPM = fraction of maximum rpm

SHP = shaft horsepower

DROT = diameter of propeller, ft

GGR = gear ratio (propeller rpm/engine rpm)

CATN = aircraft type

KWRITX= write flag

The gearbox parameters then follow as numerical functions of these quantities and are output as

GPNDB = maximum gearbox noise at 500 ft, decibels, PNdb

GDBA = maximum gearbox noise at 500 ft, decibels, DBA

WTGB = gearbox weight (including mount and afterbody), lb

CSTGB = gearbox cost, $

It may be noted that the noise is proportional to a quantity X = 10 log(SHP) which is measured in units of decibels. The scale factor is 10 instead of 20 because the power is proportional to the square of the noise, which introduces a factor of 2 into the decibel representation of the noise.

The gearbox assembly includes

- Housing
- Bearings
- Planetary Gearing
- Tailshaft
- Afterbody
- Lube and scavenge pump (single or 2-stage gearing as required)
- Fan accessory Drives

Weights are given by

Single-stage: $$W_T = 8\left[\frac{(SHP)D}{TS}\right]^{0.84} + \underset{\text{AFTERBODY}}{0.6\ D^2} \qquad \text{(for gear ratio > .20)}$$

Two-Stage: $$W_T = 10.6\left[\frac{(SHP)D}{TS}\right]^{0.84} + \underset{\text{AFTERBODY}}{0.6\ D^2}$$

(for gear ratio ≤ .20)

Gearbox cost is given by

$$CSTGB = C_1 * Z * WTGA + 13.5 * Z * WAFTB$$

where

C_1 = first unit cost ($/lb)

= 150 for single-stage planetary

= 180 for two-stage planetary

and

$Z = (LF/LF_1)$

where LF = learning curve factor for number units/yr

LF_1 = learning curve factor for first unit

Typical values for Z are

Z	= .239	NTYP	= 1 and 2
	= .283		= 3
	= .338		= 4
	= .374		= 5

Noise levels are predicted by

Single stage planetary: GPNDB = 31.0 + 10 log SHP

Two-stage planetary: GPNDB = 34.0 + 10 log SHP

and GDBA = GPNDB - 11

IV.1.3.4 Propeller Weights, Subroutine WAIT. Propeller weight is estimated in this 30-card subroutine as a numerical function of seven input parameters:

NTYP = IWTCON = airplane propeller type (1 to 5)

ZMWT = Mach number correction to propeller weight

BHP = brake horsepower

DIA = propeller diameter, ft

AFT = activity factor per blade

BLADT= number of blades

TIPSPD= tip speed, ft per sec

Then, according to several straightforward but nonlinear functions, the output parameters are simply:

WT70 = propeller weight, 1970 technology, lb

WT80 = propeller weight, 1980 technology, lb

Equations employed are

$$W_T = K_W \left[\left(\frac{D}{10}\right)^2 \left(\frac{B}{4}\right)^{0.7} \left(\frac{A.F.}{100}\right)^u \left(\frac{ND}{20,000}\right)^v \left(\frac{SHP}{10D^2}\right)^{0.12} (M+1)^{0.5} \right] + C_W$$

where

WT70 or WT80 = W_T = propeller wet weight, lbs. (excludes spinner, de-icing and governor)

DIA = D = propeller diameter, ft

BLADT = B = number of blades

AFT = A.F. = blade activity factor

N = propeller speed, rpm (take-off = $\frac{V_{TIP}}{\pi D}$; V_{TIP} = TIPSPD

BHP = SHP = shaft horsepower, HP (take-off)

ZMWT = M = Mach number (design condition: maximum power cruise)

$$C_W = y\left(\frac{D}{10}\right)^2 \left(B\right) \left(\frac{A.F.}{100}\right)^2 \left(\frac{20,000}{ND}\right)^{0.3} = \text{Counterweight Wt., lbs.}$$

K_W, C_W, u, v, and y values for use in the weight equation are taken from the table below.

Propeller Type (NTYP)	Technology 1970	1980
1	(1)	(1)
2	(2)	(2)
3	(3)	(3)
4	(3)	(4)
5	(3)	(5)

	K_W	u	v	y
(1)	170	0.9	0.35	0
(2)	200	0.9	0.35	0
(3)	220	0.7	0.40	5.0
(4)	190	0.7	0.40	3.5
(5)	190	0.7	0.30	0

Propeller types associated with above K_W and C_W are as follows:

(1) all fixed-pitch props

(2) McCauley non-counterweighted, non-feathering, constant speed props

(3) All Hartzell, all Hamilton Standard small props, and feathering McCauley

(4) Fiberglass-bladed, constant speed, counterweighted, full feathered

(5) Fiberglass-bladed, constant-speed, double-acting (non-counterweighted), full feathered, reverse

IV.1.3.5 Propeller Noises, Subroutine ZNOISE. Most of this subroutine is numerical data defining the noise generated by the propeller. The subroutine has eight other input quantities, and they are, in order:

BLADT = number of blades

DIA = propeller diameter, ft

TIPSPD = propeller tip speed, ft per sec

VKTAS = aircraft velocity, kts

BHP = brake horsepower of engine

DIST = slant distance to observer, ft

FC = $\sqrt{T_{\text{sea level}}/T_{\text{ambient}}}$

XNOE = number of engines

These quantities are then used to develop the output, which is

SPL = total perceived noise level, PNdB

SPLX = total sound pressure level, DBA

Equations employed are

$$SPL = XL1 + XL2 + XL3 + XL4 + PNLD$$

where

XL1 = ref level from Figure IV.1.9 at ref condition

XL2 = diameter and blade correction = -20[log DIA/10.5 + log BLAD/4.0]

XL3 = distance correction = -20 log DIST/500.

XL4 = number of engines correction = 10 log XNOE

PNLD = perceived noise adjustment - table look-up function of BLADT, DIA, and helical tip Mach number

IV.1.3.6 Propeller Driven Aircraft Noise Control Routine, Subroutine PNOYS. PNOYS controls noise computation for propeller aircraft. This routine is called by MAIN to get noise. As shown in Table IV.1.1 this is the third principal subroutine to get propeller and gearbox noise,; engine noise is computed with a call to ZNENG which will be described in the next subsection. PNOYS is about 45 statements in length, and it is directed principally by the argument KNOYS: i.e.,

KNOYS = 0, both Mach number and altitude are given, and noise is determined

KNOYS = 1, altitude and power setting are given, and Mach number and noise are determined.

In the latter case, Mach number is found by a call to subroutine ASPEED to find Mach number capability at altitude and power setting, and the computations after this point are independent of KNOYS.

Most of the mechanical and operational input parameters are familiar from other subroutines; e.g., DPROP is the propeller diameter, and GRAT10 is the gear ratio, etc. Other output from PNOYS is returned by subroutines ENGINE, GEARBX and XNENG, the last of which deals with noise characteristics, and it is described in the next subsection.

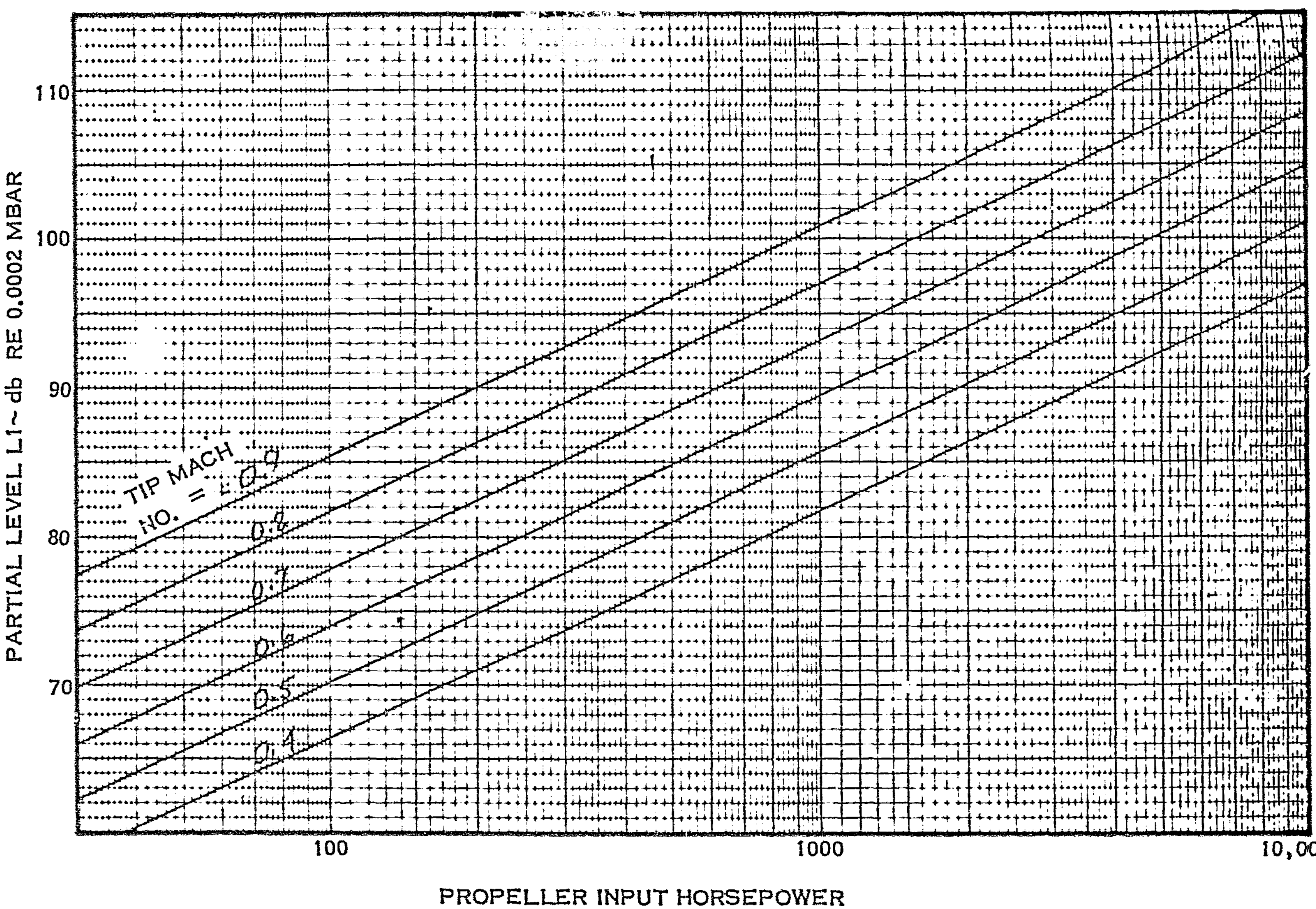

FIGURE IV.I.9 - BASIC NOISE LEVEL CURVE FOR 4-BLADED, 10.5 FT DIA. PROPELLER @ 500 FT.

IV.1.3.7 <u>Engine Noise Characteristics, Subroutine ZNENG.</u> This subroutine computes the noise characteristics of the following types of engines

JTYPE = 1, piston engine

= 2, water cooled rotary combustion engine

= 3, turboshaft engine

The noise at 500 feet distance is found assuming that the aircraft Mach number is .1, and on the basis of experimentally derived numerical expressions illustrated in Figures IV.1.10 to IV.1.12. Other descriptive inputs to the subroutine are

SHP = engine shaft horsepower

XNMAX = maximum engine rpm

PCRPM = ratio of operating rpm to maximum rpm

NOE = number of engines

GGR = gear ratio (prop rpm/engine rpm)

The output of the subroutine are the noise levels

EPNDB = perceived noise level, PNdB

EDBA = weighted level as measured on the A-scale, for which the noise levels are reduced at low and high frequencies, dbA

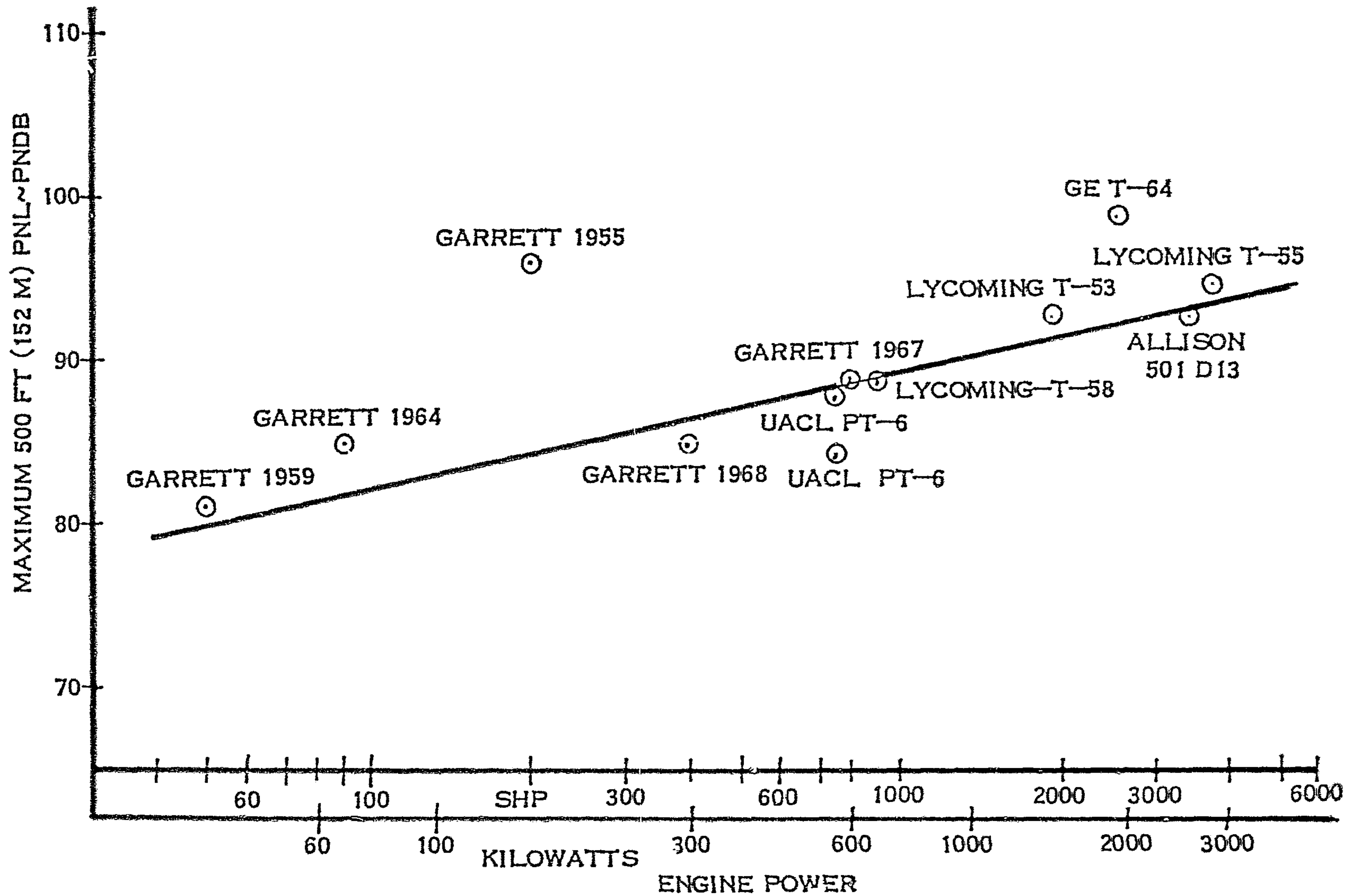

FIGURE IV.I.IO - NOISE OF UNMUFFLED GAS TURBINE ENGINE

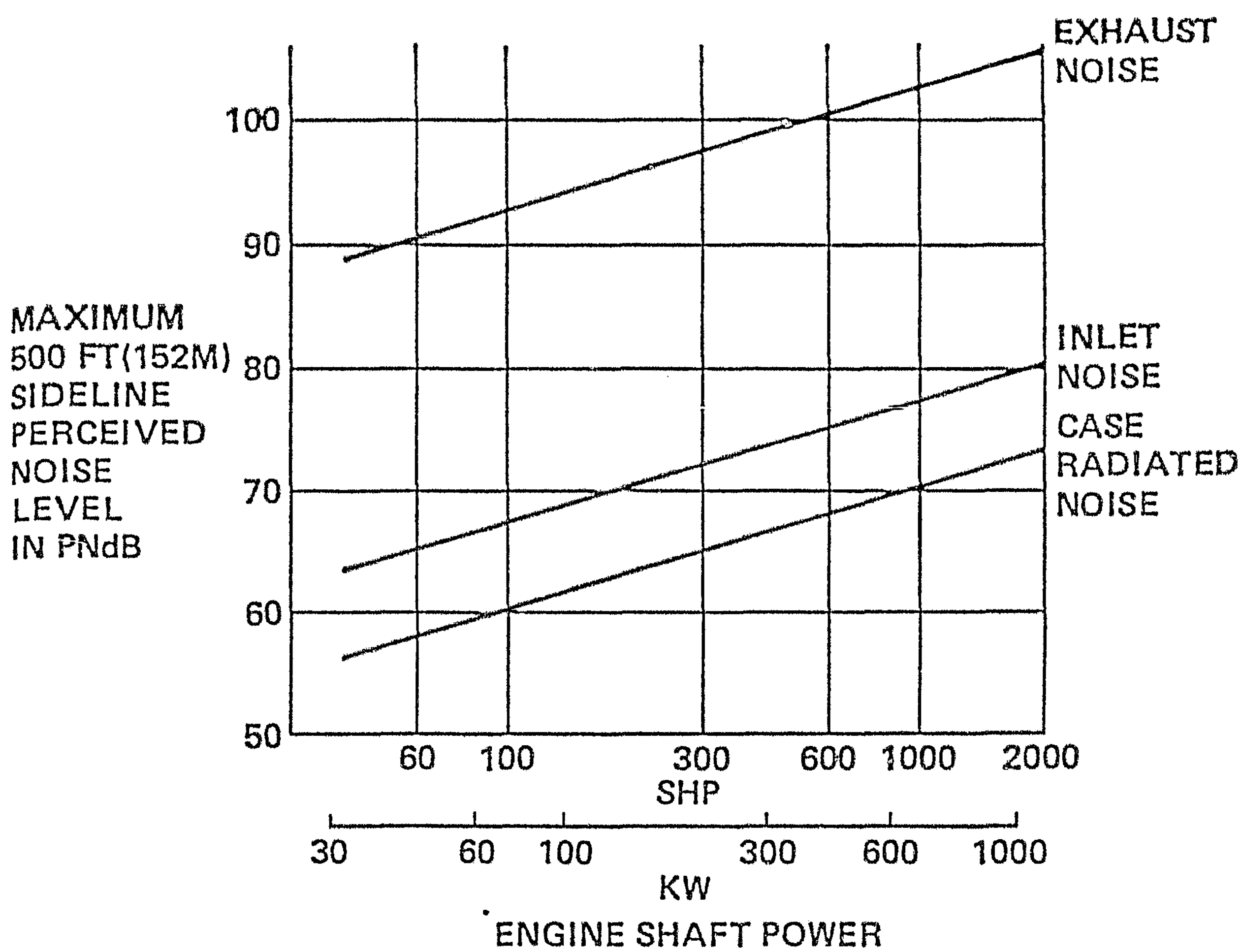

FIGURE IV.I.II - NOISE OF UNMUFFLED WATER COOLED ROTARY COMBUSTION ENGINES

FIRING FREQUENCY = $\frac{\text{ENGINE RPM}}{60}$ *N*NCYL

WHERE: N = 0.5 FOR FOUR CYLINDER

N = 1.0 FOR TWO CYLINDER

NCYL = NUMBER OF CYLINDERS

RPM	NCYL	F.F.
3400	6	170
2700	6	135
1500	6	75
2700	4	90
2000	4	66.7

dBA = PNdB - 12.

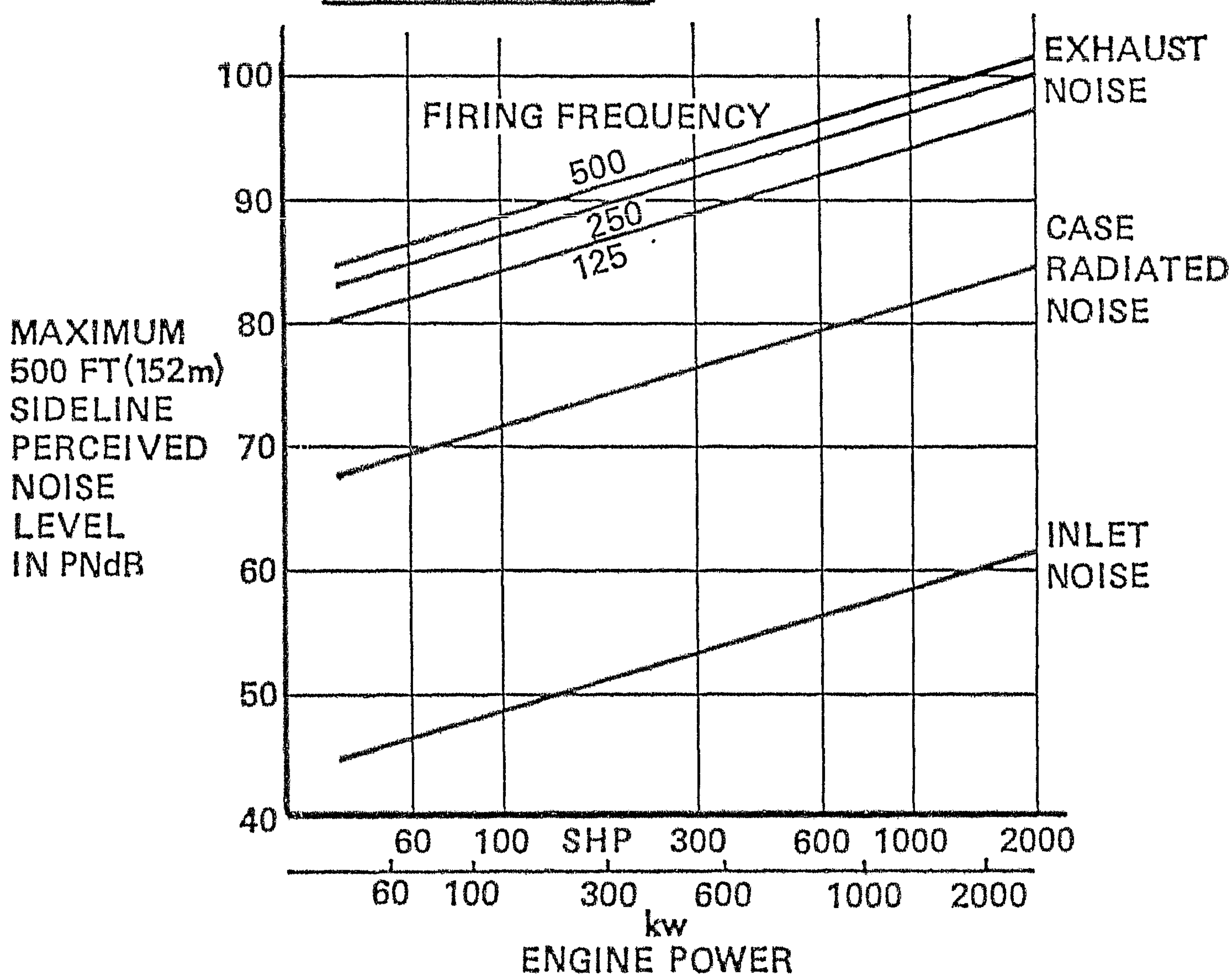

FIGURE IV.I.10 - NOISE OF UNMUFFLED PISTON ENGINES

GASP - GENERAL AVIATION SYNTHESIS PROGRAM

VOLUME IV - PROPULSION

PART 2 - USER'S MANUAL

JANUARY 1978

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Ames Research Center
Moffett Field, California

Under

CONTRACT NAS 2-9352

AEROPHYSICS RESEARCH CORPORATION

IV.2 PROPULSION MODEL USER'S MANUAL

The propulsion model subroutines are very numerous, whether the system is of turbofan or propeller in form. The present section alphabetically tabulates and defines the input/output parameters for all the propulsion subroutines, with turbofan programs followed by propeller programs. These tabulations follow the order given below.

Turbofan Subroutines	Propeller Subroutines	
ENGDT1-7	COST	PNOYS
ENGDTT	ENGDAT	PWRPLT
ENGINE	ENGINE	TURBEG
ENGSZ	ENGSZ	WAIT
NACDG	GEARBX	ZNENG
	PERFM	ZNOISE

Many of the subroutines are devoted principally to the tabulation of a specific propulsion system performance data, and in these cases only a few additional input-output quantities are listed. On the other hand, the very long programs (ENGSZ and PERFM, for example) are associated with many such parameters. As will be seen, the propeller systems generally require a greater number of input parameters than do the turbofan systems.

The seven subroutines listed below are not tabulated because they deal with numerical performance characteristics of a group of aircraft turbofan/ turbojet jet engines:

ENGDT1 = GE CJ610-6 Turbojet

ENGDT2 = Garrett TFE 731-2 Turbofan

ENGDT3 = UACL JT15D-1 Turbofan

ENGDT4 = Lycoming ALF-502 Turbofan

ENGDT5 = GE CF34 Turbofan

ENGDT6 = GE TF34 Turbofan

ENGDT7 = QCGAT Turbofan

FIGURE IV.2.1 SUBROUTINE ENGDTT (TURBOFAN)--INPUT

VARIABLE	DESCRIPTION
FTHROT	power setting as a fraction of maximum
HN	altitude, ft
KENG	engine power setting indicator (0 to 7)
NALT	number of altitudes in tables
NMN	number of Mach numbers in table
NT4	number of turbine inlet temperature ratios T4/T2 in table
P2	total pressure, lb per sq ft
SFNIDL	idle specific thrust, lb per lb/sec
SM	Mach number
T2	total temperature, deg R
T4MAX	maximum turbine inlet temperature, deg R
T4MC	turbine inlet temperature in cruise configuration, deg R
T4MCL	turbine inlet temperature in climb configuration, deg R
WAMAP	maximum sea level static airflow of reference engine at 100 per cent corrected rotor speed, lb per sec.

FIGURE IV.2.2 SUBROUTINE ENGDTT--OUTPUT

VARIABLE	DESCRIPTION
FAR	fuel air ratio
FN	thrust, lb
PCWAC	ratio of corrected airflow to maximum sea level static airflow
SFC	specific fuel consumption, lb per hr per lb of thrust
SFN	specific thrust; lb per lb per sec of airflow
WA	airflow, lb per sec
WF	fuel flow, lb per hr

FIGURE IV.2.3 SUBROUTINE ENGINE (TURBOFAN)--INPUT

VARIABLE	DESCRIPTION
FAR	fuel-air ratio
FN	thrust, lb
HN	altitude, ft
IENGSC	engine cycle indicator
ISEGX	mission segment indicator
KENG	engine power setting indicator
KNAC	nacelle drag/sizing indicator
KODEAC	acceleration segment power setting indicator
KODECL	climb segment power setting indicator
KODETO	takeoff segment power setting indicator
KODETR	turn segment power setting indicator
KWRITE	write indicator
PCWAC	ratio of corrected airflow to maximum sea level static airflow
PR	inlet pressure recovery factor
PO	static pressure, lb per sq ft
SFC	specific fuel consumption, lb per hr per lb of thrust
SMN	Mach number
TO	static temperature, deg R
WASLS	sea level static airflow, lb per sec
WG	design gross weight, lb
WGS	wing loading, lb per sq ft

FIGURE IV.2.4 SUBROUTINE ENGINE--OUTPUT

VARIABLE	DESCRIPTION
FN	thrust, lb.
KODE	engine power setting indicator
WF	fuel flow, lb per hr

FIGURE IV.2.5 SUBROUTINE ENGSZ (TURBOFAN)--INPUT

VARIABLE	DESCRIPTION
CDNI	nacelle skin friction coefficient
CLMXLD	maximum lift coefficient in landing configuration
CLMXTO	maximum lift coefficient in takeoff configuration
DCLTO	lift coefficient increment in takeoff configuration
DRG	total drag, lb
DRGNC1	nacelle drag, lb
EM	Mach number
EMTURN	Mach number in steady turn
ENP	number of engines
H	altitude, ft
HBTP	hub to tip ratio of fan
HPORT	airport altitude, ft
HTURN	turn altitude, ft
ICRU	indicator used when KNAC = 0 (nacelle drag = thrust loss)
IEGWGT	indicator to determine if engine dimensions are to be calculated by ENGWGT
JENGSZ	engine sizing option indicator
KNAC	nacelle drag sizing indicator
NACDRG	indicates if engine dimensions have been calculated external to ENGSZ
NPC	computation indicator
NTYE	type of engine indicator
NTYP	type of propeller indicator

VARIABLE	DESCRIPTION
PCWAC	ratio of corrected airflow to maximum SLS airflow
PO	static pressure, lb per sq ft
RCCRU	required cruise rate of climb capability, ft per min
RWCRTO	ratio of cruise weight to takeoff weight
SFNSLS	specific thrust, sea level static, lb per lb per sec
SM1D	fan face Mach number, assuming one-dimensional flow
SW	wing area, sq ft
TDELTO	temperature deviation from standard day, for takeoff engine sizing
THIN	input thrust per engine (JENGSZ = 4)
TO	static temperature, deg R
WF	fuel flow, lb per hr
WG	gross weight, lb
WGS	wing loading, lb per sq ft
WTRFAC	weight during turn divided by maximum gross weight
XCKN	nacelle form factor
XLFTRN	turn load factor
XLQDE	nacelle length to diameter ratio
XTO	actual takeoff distance, ft
XTORQ	required takeoff distance, ft

FIGURE IV.2.6 SUBROUTINE ENGSZ-- OUTPUT

VARIABLE	DESCRIPTION
AE	flow area at fan face, sq ft
ANAC	nacelle surface area, sq ft
CDNAC	nacelle drag coefficient
CLTLMT	limit lift coefficient during turn
EM	Mach number
ENP	number of engines
FNSLS	sea level static thrust, lb
IDC	control flag
IPART	FAR regulation part indicator for climb sizing
ISEGX	flight segment indicator
ITRSZ	engine sizing for turn indicator
KSIZE	engine sizing flag for takeoff
RELI	Reynolds number per foot
W	current aircraft weight, lb
WASLS	sea level static airflow, lb per sec
XLN	nacelle length, ft
YCLB	used in subroutine NACDG for including nacelle drag as engine thrust loss
YDRG	used in subroutine NACDG for including nacelle drag as engine thrust loss
ZLQD	lift to drag ratio

FIGURE IV.2.7 SUBROUTINE NACDG (TURBOFAN)--INPUT

VARIABLE	DESCRIPTION
ANAC	surface area of nacelle, sq ft
CDN1	reference drag coefficient of nacelle
ENPP	number of engines
ICRU	engine sizing/performance flag
KWRITE	print indicator
PO	static pressure, lb per sq ft
RELI	Reynolds number per unit length, per ft
SMN	Mach number
SWING	wing area, sq ft
XCKN	nacelle form factor
XLN	nacelle length
XLQDE	engine (nacelle) length/diameter ratio
YCLB	thrust increment required to provide cruise climb margin, lb.
YDRG	cruise drag, level flight, lb.

FIGURE IV.2.8 SUBROUTINE NACDG--OUTPUT

VARIABLE	DESCRIPTION
DRGNCi	drag of one nacelle, lb.
SFC	specific fuel consumption, corrected for nacelle drag
SFN	specific thrust lb/lb/sec FN/Wa, corrected for nacelle drag
WA	airflow, lb/sec, corrected for nacelle drag

FIGURE IV.2.9 SUBROUTINE ENGSZ (PROPELLER)—INPUT

VARIABLE	DESCRIPTION
ANCQHP	nacelle area per unit power, sq ft per hp
BD	fuselage diameter, ft
BLANG	blade angle, deg
CLMXLD	maximum lift coefficient at landing
CLMXTO	maximum lift coefficient at takeoff
DCLTO	lift coefficient increment in takeoff configuration
DRGC	cruise drag, lb
EM	Mach number
EMCRU	cruise Mach number
ENP	number of engines
H	altitude, ft
HPMSLS	maximum sea level static horsepower
HPORT	airport altitude above SL, ft
IEGWGT	engine weight indicator set in MAIN
JENGSZ	engine sizing flag, see NAMELIST INGASP
JSIZE	engine power flag, see NAMELIST INGASP
KCONFG	boom or conventional tail indicator, see NAMELIST INGASP
KNAC	nacelle drag flag, see NAMELIST INGASP
KWRITE	program print flag; see NAMELIST INGASP
NACDRG	indicator used by RGBAL to keep track of nacelle drag
NPC	path indicator
NSC	subroutine indicator
NTYE	engine type indicator; see NAMELIST INGASP

VARIABLE	DESCRIPTION
NTYP	propeller type indicator
PCPCR	per cent maximum power in cruise for reciprocating engines
PCRCR	per cent maximum rpm in cruise for reciprocating engines
PR	nacelle inlet pressure recovery factor
PO	static pressure, lb per sq ft
RCCRU	required cruise rate of climb capability, ft per min
RELI	Reynolds number per unit length, per ft
RPM	engine speed, rev per min
RWCRTO	ratio of weight at cruise to gross weight
SW	wing area, sq ft
TDELTO	temperature deviation from standard, deg F
TSPDMX	maximum propeller static tip speed, ft per sec
TO	static temperature, deg R
WG	gross weight, lb
WGS	wing loading, lb per sq ft
XCKN	nacelle form factor
XLQDE	nacelle length to diameter ratio
XNMAX	maximum engine speed, rpm
XTO	actual takeoff distance, ft

FIGURE IV.2.10 SUBROUTINE ENGSZ—OUTPUT

VARIABLE	DESCRIPTION
ANAC	nacelle surface area, sq ft
CDNAC	drag coefficient of nacelles based on wing area
DPROP	propeller diameter, ft
EM	Mach number
GRATIO	gear ratio, propeller rpm/engine rpm
H	altitude, ft
HNCRU	cruise altitude, ft
HPMSLS	sea level static maximum horsepower
IDC	special purpose indicator
IPART	FAR part 23/25 climb requirement indicator
ISEGX	segment indicator
KFPTCH	fixed pitch propeller indicator
KSIZE	engine takeoff sizing indicator
PCPOWR	fraction of maximum power
PCRPM	fraction of maximum rpm
PO	static pressure, lb per sq ft
RELI	Reynolds number per unit length, per ft
TO	static temperature, deg R
XLN	nacelle length, ft
XTORQ	takeoff distance required to clear 35 ft altitude, ft
XLQD	lift to drag ratio

FIGURE IV.2.11 SUBROUTINE ENGINE (PROPELLER)—INPUT

VARIABLE	DESCRIPTION
AF	propeller blade activity factor per blade
BL	number of propeller blades
BLANG	propeller blade angle at 3/4 radius, deg.
COD	QFAN shroud fineness ratio
CP	propeller power coefficient
CPROP	propeller cost, $
CQFT	cost of "Q-FAN" propulsor, $
CTI	initial estimate of propeller thrust coefficient
DPROP	propeller diameter, ft.
ENP	number of engines
FT	propeller slipst[illegible]or; fraction of thrust lost ($T_{effective}/T_{isolated}$)
GR	gear ratio; propeller rpm/engine rpm
H	altitude, ft.
HCRIT	critical altitude for turbocharged engine
HPAVLB	horsepower available
HPM	maximum horsepower at given altitude
HPMSLS	maximum horsepower at sea level standard conditions
ISEGX	mission segment indicator
KENG	power setting indicator
KODE	engine sizing, power and flight condition options, defined in ENGINE
KODECR	reciprocating/turboprop engine cruise sizing option; see namelist INPROP

VARIABLE	DESCRIPTION
KODETH	reciprocating/turboprop engine throttling options
KSPCHG	supercharger indicator; see namelist INPROP
KWRITE	subroutine print option; see namelist INGASP
NTYE	engine type indicator; see namelist INGASP
NTYP	propeller type indicator; see namelist INPROP
PCNCCL	per cent corrected rotor speed at climb, turboprop; see namelist INPROP
PCNCCR	per cent corrected rotor speed at cruise, turboprop; see namelist INPROP
PCNCTO	per cent corrected rotor speed at takeoff, turboprop; see namelist INPROP
PCPCL	per cent maximum power in climb, reciprocating engine; see namelist INPROP
PCPTO	per cent maximum power at takeoff, reciprocating engine; see namelist INPROP
PCRCL	per cent maximum rpm in climb, reciprocating engine; see namelist INPROP
PCRCR	per cent maximum rpm in cruise, reciprocating engine; see namelist INPROP
PCRTO	per cent maximum rpm at takeoff, reciprocating engine, see namelist INPROP
PO	static pressure, lb per sq ft
SHP	shaft horsepower required to turn propeller

VARIABLE	DESCRIPTION
SMN	Mach number
THRUST	thrust, lb
TO	standard atmospheric temperature, deg R
TSPDMX	maximum propeller tipspeed, ft per sec
T4STCL	turboprop turbine inlet temperature at climb, deg R
T4STCR	turboprop turbine inlet temperature at cruise, deg R
T4STTO	turboprop turbine inlet temperature at takeoff, deg R
WQFT	weight of "Q-FAN" propulsor
XJ	advance ratio
XNMAX	maximum engine speed, rpm

FIGURE IV.2.12 SUBROUTINE ENGINE--OUTPUT

VARIABLE	DESCRIPTION
CT	propeller thrust coefficient
HPWR	engine power output, hp
KERROR	error indicator
KFPTCH	fixed pitch propeller indicator set by NTYP
KWRITY	write indicator
PCPOWR	engine power output, hp
PCRPM	percent of maximum engine rpm
RPM	engine rpm
SIGCRT	density ratio at critical altitude for supercharged reciprocating engine
THRUST	propeller thrust, lb
TSFC	thrust specific fuel consumption, lb per hr per lb
WF	fuel flow, lb per hr

FIGURE IV.2.13 SUBROUTINE ENGDAT (PROPELLER)—INPUT

VARIABLE	DESCRIPTION
AFX	propeller blade activity factor
ASTERK	error flag if there is problem in calculating propeller performance
BLX	number of propeller blades
CAMT	production quantity of propellers to be used (default or input in namelist INPROP)
CLI	design integrated lift coefficient of propeller
DIST	slant distance to observer for noise
DROT	propeller diameter
EM	Mach number
EMCRU	cruise Mach number
ENP	number of engines
GR	gear ratio, ratio of propeller rpm to engine rpm
IDATE	propeller technology level (1970 or 1980)
KNAC	nacelle drag indicator
KODE	engine performance options defined in subroutine ENGINE
KWRITE	print indicator
PCRPM	fraction of maximum rpm
RORO	ratio of air density to standard sea level density
TO	temperature, deg R
VKTS	airspeed, kts
WKPFAC	propeller weight adjustment factor
XCK70	single unit propeller cost (1970),$ per lb

VARIABLE	DESCRIPTION
XCK80	single unit propeller cost (1980), $ per lb
XCLF	learning curve factor for yearly units (1.02)
XCLF1	learning curve factor for single unit (3.2178)
XFT	propeller compressibility correction (0, no compressibility
XNMAX	maximum engine speed, rev per min

FIGURE IV.2.14 SUBROUTINE ENGDAT--OUTPUT

VARIABLE	DESCRIPTION
AF	propeller activity
BL	number of propeller blades
BLANG	propeller blade angle at 3/4 radius, deg
BLLL	propeller blade angle at 3/4 radius, deg
CP	power coefficient
CPROP	propeller cost, $
CSTGB	gear box cost, $
CT	thrust coefficient
EFFP	propeller efficiency
IERROR	error indicator
NTYP	propeller type indicator
SHP	shaft horsepower
THRUST	total propeller thrust, lb
WROP01	weight of one propeller, lb
WTGB	gear box weight, lb
ZJI	advance ratio
ZMWT	cruise Mach number

FIGURE IV.2.15 SUBROUTINE COST (PROPELLER)--INPUT

VARIABLE	DESCRIPTION
BLADT	number of propeller blades
CAMT	input value of CQUAN(I), if positive
CK70	input value of CCK70, if positive
CK80	input value of CCK80, if positive
CLF	learning curve factor for a number of units per year
CLF1	learning curve factor for a single unit
IENT	= 1, define CCLF and CCLF1 then return
	= 2, compute propeller cost
WTCON	propeller category: fixed pitch, constant speed, etc.)
WT70	propeller weight, 1970 technology
WT80	propeller weight, 1980 technology
ZEFAC(J)	empirical factor multiplying propeller cost, category J
ZFFAC(I, J)	single unit propeller cost factor, year I, category J
ZQUAN(I, J)	number of propellers produced in year I of category J

FIGURE IV.2.16 SUBROUTINE COST--OUTPUT

VARIABLE	DESCRIPTION
CCK70	average original equipment manufacturer 1970 propeller cost, $ per lb
CCK80	average original equipment manufacturer 1980 propeller cost, $ per lb
CCLF	learning curve factor for a number of units per year
CCLF1	learning curve factor for a single unit
COST70	propeller cost, 1970 technology, $
COST80	propeller cost, 1980 technology, $
CQUAN(I)	number of propellers produced in year I

FIGURE IV.2.17 SUBROUTINE GEARBX (PROPELLER)-INPUT

VARIABLE	DESCRIPTION
CATN	propeller type indicator set according to value input for NTYP
DROT	propeller diameter, ft
GGR	gear ratio
KWRITX	write indicator
MODE	= 1, compute gear box weight
	= 2, compute cost
	= 3, compute noise
PCRPM	fraction of maximum rpm
SHP	propeller shaft horsepower

FIGURE IV.2.18 SUBROUTINE GEARBX--OUTPUT

VARIABLE	DESCRIPTION
CSTGB	cost of gearbox, dollars
GDBA	gear box noise, dBA
GPNDB	gearbox noise , PNdB
WTGB	gearbox weight, lb

FIGURE IV.2.19 SUBROUTINE PERFM (PROPELLER)--INPUT

VARIABLE	DESCRIPTION
AFT	activity factor per blade
BLADT	number of blades per propeller
BLLL	blade angle, deg
CLI	propeller blade integrated design coefficient
CT	thrust coefficient
IW	type of computation flag
LIMIT	error return flag
XFT	propeller compressibility factor
ZJI	advance ratio
ZMS	propeller Mach number

FIGURE IV.2.20 SUBROUTINE PERFM--OUTPUT

VARIABLE	DESCRIPTION
AFCPE	activity factor adjustment on effective power coefficient
AFCTE	activity factor adjustment on effective thrust coefficient
ASTERK	error return flag
BLLL	blade angle, deg
CP	power coefficient
CPE	effective power coefficient
CTE	effective thrust coefficient
XFT	propeller compressibility factor

FIGURE IV.2.21 SUBROUTINE PNOYS (PROPELLER)--INPUT

VARIABLE	DESCRIPTION
DPROP	propeller diameter, ft
EM	Mach number
ENP	number of engines
GRATIO	gear ratio; propeller rpm to engine rpm
H	altitude, ft
HPMSLS	maximum sea level static horsepower
KNOYS	noise calculation flag
KWRITE	output print flag
NTYE	engine type indicator
NTYP	propeller type indicator
WF	fuel flow, lb per hr
WG	aircraft gross weight, lb
XNMAX	maximum engine speed, rpm

FIGURE IV.2.22 SUBROUTINE PNOYS--OUTPUT

VARIABLE	DESCRIPTION
EM	Mach number
H	altitude, ft
ISEGX	mission segment indicator
PCRPM	per cent maximum rpm
PCRTO	per cent maximum takeoff rpm

FIGURE IV.2.23 SUBROUTINE PWRPLT (PROPELLER)--INPUT

VARIABLE	DESCRIPTION
BMEP	brake mean effective pressure, lb per sq in
DELTA	ratio of static pressure to sea level static pressure
H	altitude, ft
KODE	engine sizing options defined in subroutine ENGINE
KSPCHG	supercharger flag
RTHET	square root of temperature ratio
XNMAX	maximum engine rpm

FIGURE IV.2.24 SUBROUTINE PWRPLT--OUTPUT

VARIABLE	DESCRIPTION
BSFC	specific fuel consumption, lb per hr per hp
HPAVLB	maximum full throttle horsepower available at altitude at operating rpm
HPM	maximum horsepower available at altitude
HPMSLS	maximum sea level static horsepower
HPWR	engine power output, hp
PCPOWR	per cent maximum power
SIGCRT	critical air density ratio for supercharged engine

FIGURE IV.2.25 SUBROUTINE TURBEG (PROPELLER)--INPUT

VARIABLE	DESCRIPTION
HPWR	engine power output, hp
KODE	engine and flight condition options defined in ENGINE
KWRITE	write indicator
MODEP	0, sets maximum power setting for continuous operation
	1, higher maximum power setting for takeoff
PO	static pressure at altitude, lb per sq ft
SMN	Mach number
TO	static temperature at altitude, deg R
TRSET	turbine inlet temperature, deg R

FIGURE IV.2.26 SUBROUTINE TURBEG--OUTPUT

VARIABLE	DESCRIPTION
FN	turboprop jet thrust, lb
GR	gear ratio; propeller speed to engine speed
HPAVLB	turboprop power output
HPMSLS	maximum sea level static horsepower
PCN	per cent maximum rotor speed
PCNCR	per cent corrected maximum rotor speed
WF	fuel flow, lb per hr
XNMAX	maximum engine rpm

FIGURE IV.2.27 SUBROUTINE WAIT (PROPELLER)--INPUT

VARIABLE	DESCRIPTION
AFT	activity factor per blade
BHP	brake horsepower
BLADT	number of propeller blades
DIA	propeller diameter, ft
TIPSPD	propeller tip speed, ft per sec
WTCON	parameter defining aircraft category
ZMWT	Mach number correction on propeller weight

FIGURE IV.2.28 SUBROUTINE WAIT--OUTPUT

VARIABLE	DESCRIPTION
WT70	propeller weight, 1970 technology, lb
WT80	propeller weight, 1980 technology, lb

FIGURE IV.2.29 SUBROUTINE ZNENG (PROPELLER)--INPUT

VARIABLE	DESCRIPTION
ITYPE	type of engine indicator set according to NTYE
NOE	number of engines
PCRPM	fraction of maximum rpm
SHP	,aft horsepower
XNMAX	maximum engine speed, rev par min

FIGURE IV.2.30 SUBROUTINE ZNENG--OUTPUT

VARIABLE	DESCRIPTION
EDBA	noise level, dBA
EPNDB	noise level, PNdB

FIGURE IV.2.31 SUBROUTINE ZNOISE (PROPELLER)--INPUT

VARIABLE	DESCRIPTION
BHP	brake horsepower
BLADT	number of propeller blades
DIA	propeller diameter, ft
DIST	slant distance to observer, ft
FC	square root of temperature ratio
TIPSPD	propeller tip speed, ft per sec
VKTAS	TAS, kts
XNOE	number of engines

FIGURE IV.2.32 SUBROUTINE ZNOISE--OUTPUT

VARIABLE	DESCRIPTION
SPL	sound pressure level PNDB

GASP - GENERAL AVIATION SYNTHESIS PROGRAM

VOLUME IV - PROPULSION

PART 3 - PROGRAMMERS' MANUAL

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Moffett Field, California

Under

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AEROPHYSICS RESEARCH CORPORATION

IV.3 PROPULSION MODEL AND PROGRAMMER'S MANUAL

The flow charts of the propulsion subroutines are shown in alphabetic order, for both turbofan and propeller systems. A total of 23 subroutines have been drawn and are presented in the following alphabetic order:

Turbofan Subroutines		Propeller Subroutines
ENGDT1-7	TYPIFIED BY ENGDTI	• COST
ENGDTT		• ENGDAT
• ENGINE		• ENGINE
• ENGSZ		• ENGSZ
• NACDG		• GEARBX
		• PERFM
		• PNOYS
		• PWRPLT
		• TURBEG
		• WAIT
		• ZNENG
		• ZNOISE

The flow charts do not include the presentation of numerical performance data, which is a large portion of many of the routines. On the other hand, the interdependence among the routines can be appreciated by noting the subroutines of each.

IV.3.1 Turbojet and Turbofan Routines

IV.3.1.1 Subroutine ENGINE, Turbojet and Turbofan Engine Performance at Specified Flight Condition. This routine computes turbojet and turbofan thrust, airflow, fuel flow, specific thrust, per cent corrected airflow, and thrust specific fuel consumption at a specified altitude and Mach number. Figure IV.3.1 provides a detailed flow chart of this subroutine. Routine operation is described in Section IV.1.1.1.

The various engine sizing options are controlled by the indicator KENG. Engine type selection is controlled by the indicator IENGSC which takes one of eight values to call the engine type desired. Basic engine types available are contained in the subroutines ENGDT1 to ENGDT7 and ENGDTT. Subroutine NACDG is used to compute nacelle drag losses. Engine iterations are carried out with the aid of subroutine ITRMHW, described in Section I.1.3.8.

ENGINE

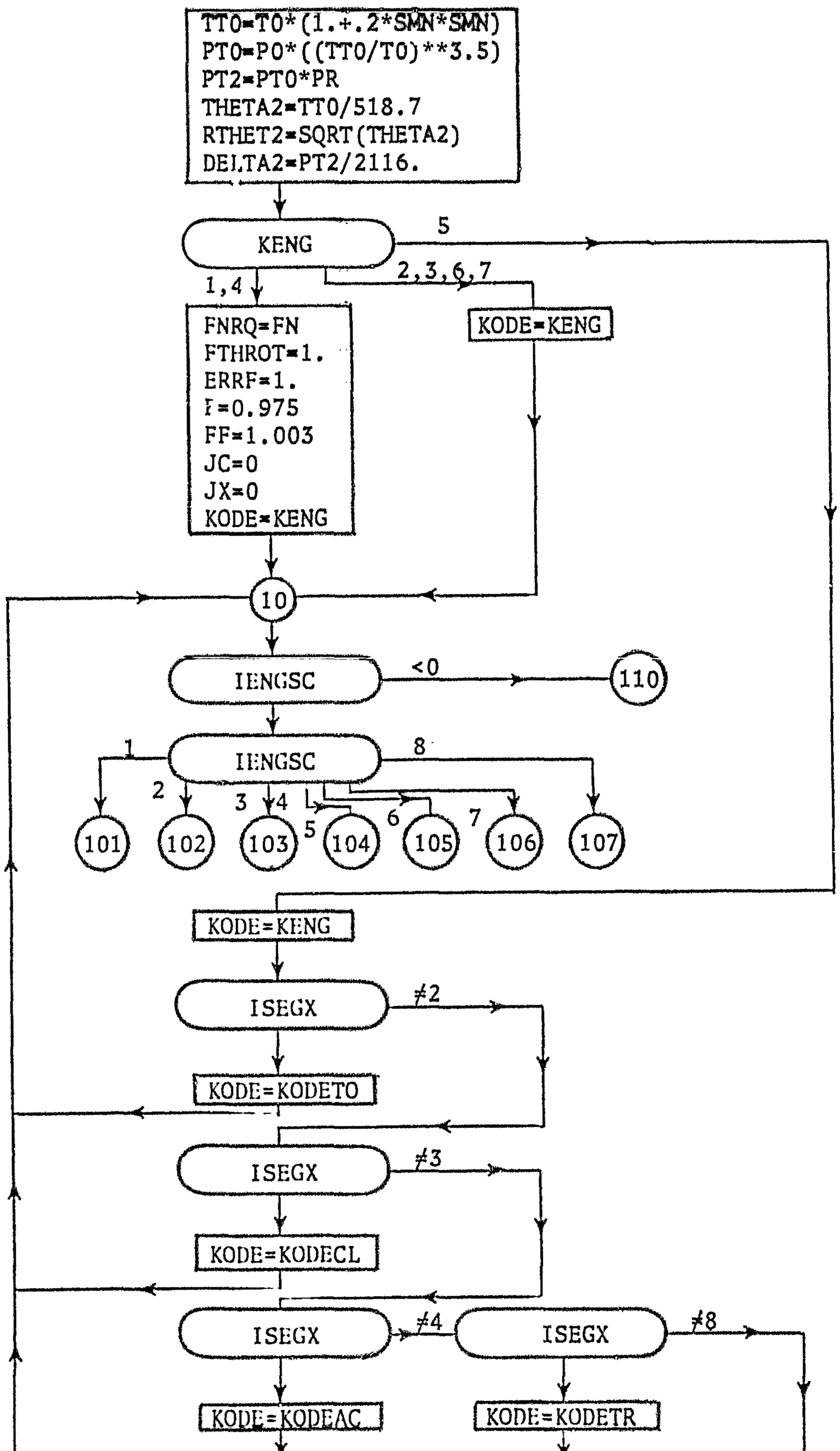
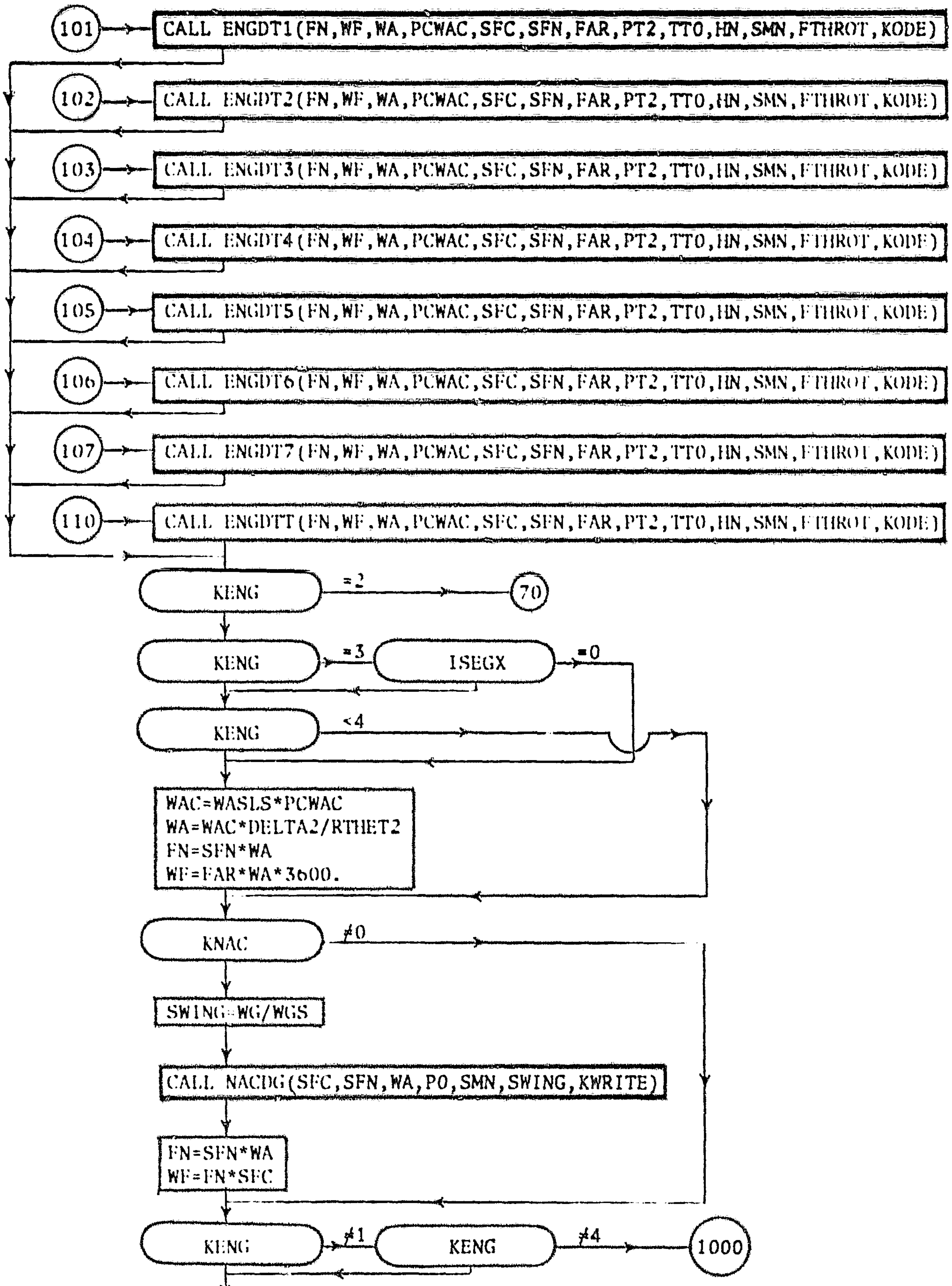
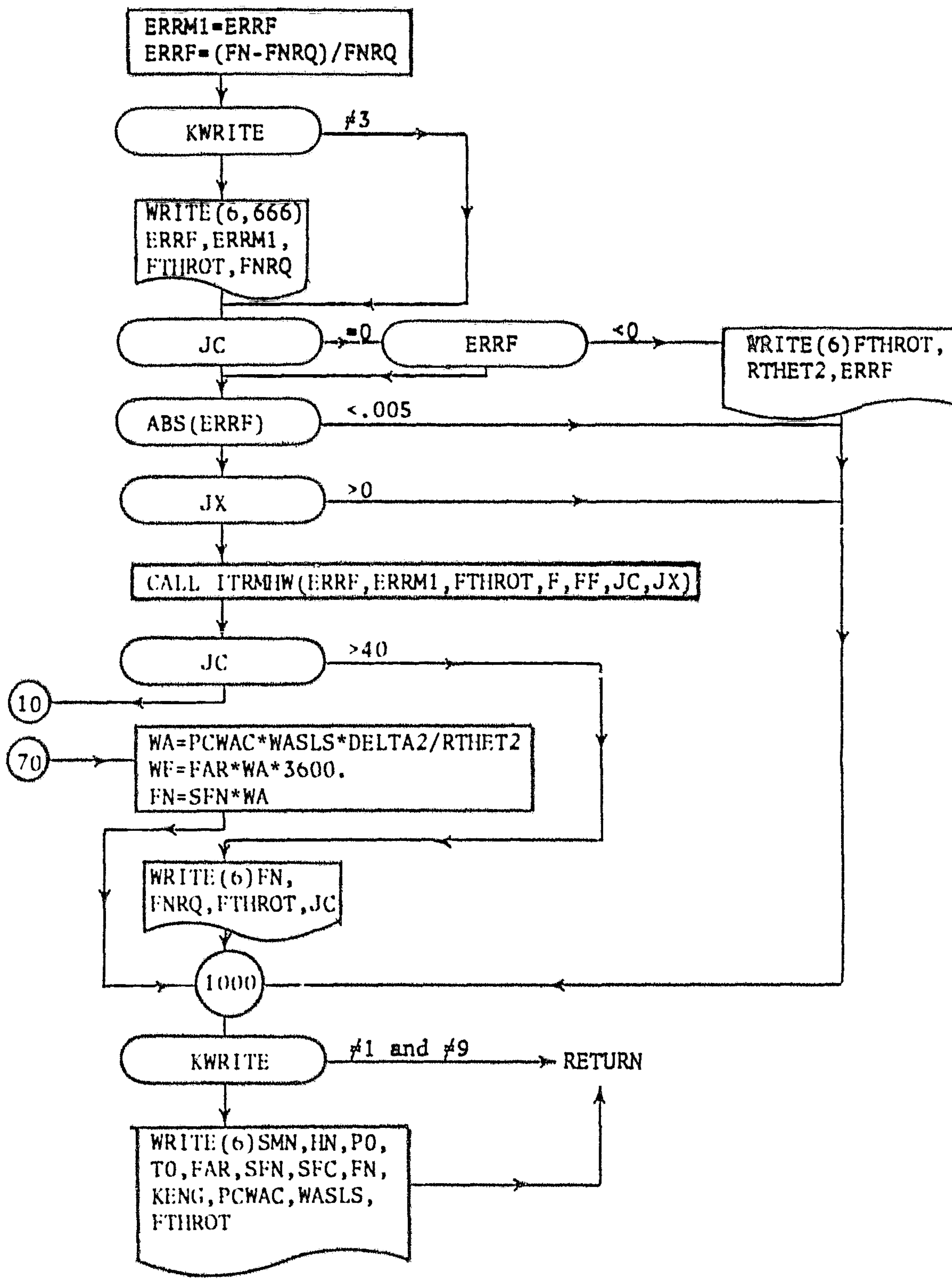


FIGURE IV.3.1 - DETAILED FLOWCHART, SUBROUTINE ENGINE


101
CALL ENGDT1(FN,WF,WA,PCWAC,SFC,SFN,FAR,PT2,TT0,HN,SMN,FTHROT,KODE)
102
CALL ENGDT2(FN,WF,WA,PCWAC,SFC,SFN,FAR,PT2,TT0,HN,SMN,FTHROT,KODE)
103
CALL ENGDT3(FN,WF,WA,PCWAC,SFC,SFN,FAR,PT2,TT0,HN,SMN,FTHROT,KODE)
104
CALL ENGDT4(FN,WF,WA,PCWAC,SFC,SFN,FAR,PT2,TT0,HN,SMN,FTHROT,KODE)
105
CALL ENGDT5(FN,WF,WA,PCWAC,SFC,SFN,FAR,PT2,TT0,HN,SMN,FTHROT,KODE)
106
CALL ENGDT6(FN,WF,WA,PCWAC,SFC,SFN,FAR,PT2,TT0,HN,SMN,FTHROT,KODE)
107
CALL ENGDT7(FN,WF,WA,PCWAC,SFC,SFN,FAR,PT2,TT0,HN,SMN,FTHROT,KODE)
110
CALL ENGDTT(FN,WF,WA,PCWAC,SFC,SFN,FAR,PT2,TT0,HN,SMN,FTHROT,KODE)
KENG
=2
70
KENG
=3
ISEGX
=0
KENG
<4
WAC=WASLS*PCWAC
WA=WAC*DELTA2/RTHET2
FN=SFN*WA
WF=FAR*WA*3600.
KNAC
≠0
SWING=WG/WGS
CALL NACDG(SFC,SFN,WA,P0,SMN,SWING,KWRITE)
FN=SFN*WA
WF=FN*SFC
KENG
≠1
KENG
≠4
1000


ERRM1=ERRF
ERRF=(FN-FNRQ)/FNRQ
KWRITE
≠3
WRITE(6,666) ERRF,ERRM1, FTHROT,FNRQ
JC
=0
ERRF
<0
WRITE(6)FTHROT, RTHET2,ERRF
ABS(ERRF)
<.005
JX
>0
CALL ITRMHW(ERRF,ERRM1,FTHROT,F,FF,JC,JX)
JC
>40
10
70
WA=PCWAC*WASLS*DELTA2/RTHET2
WF=FAR*WA*3600.
FN=SFN*WA
WRITE(6)FN, FNRQ,FTHROT,JC
1000
KWRITE
≠1 and ≠9
RETURN
WRITE(6)SMN,HN,PO, TO,FAR,SFN,SFC,FN, KENG,PCWAC,WASLS, FTHROT

IV.3.1.2 <u>Subroutine ENGSZ, Turbojet and Turbofan Engine Sizing</u>. This routine controls turbojet and turbofan engine sizing computations. Routine function is described in Section IV.1.1. Engine characteristics are determined by calls to subroutine ENGINE. Nacelle characteristics are controlled by the indicator KNAC. Sizing method is controlled by the indicator JENGSZ. Subroutine PERFM is used to compute take-off performance. Engine weights are computed by a call to subroutine ENGWGT (described in Volume V). Subroutine TPALT (Section I.1.3.15) is used to obtain atmospheric properties. Flap setting are determined by a call to subroutine APPFLP which is described in Section III.1.4.4. Configuration drag is determined by a call to subroutine DRAG (Section III.1.2.2). Where engines are sized in turning flight, subroutine TURN is used (Volume VI).

A detailed flow chart for subroutine ENGSZ is presented in Figure IV.3.2.

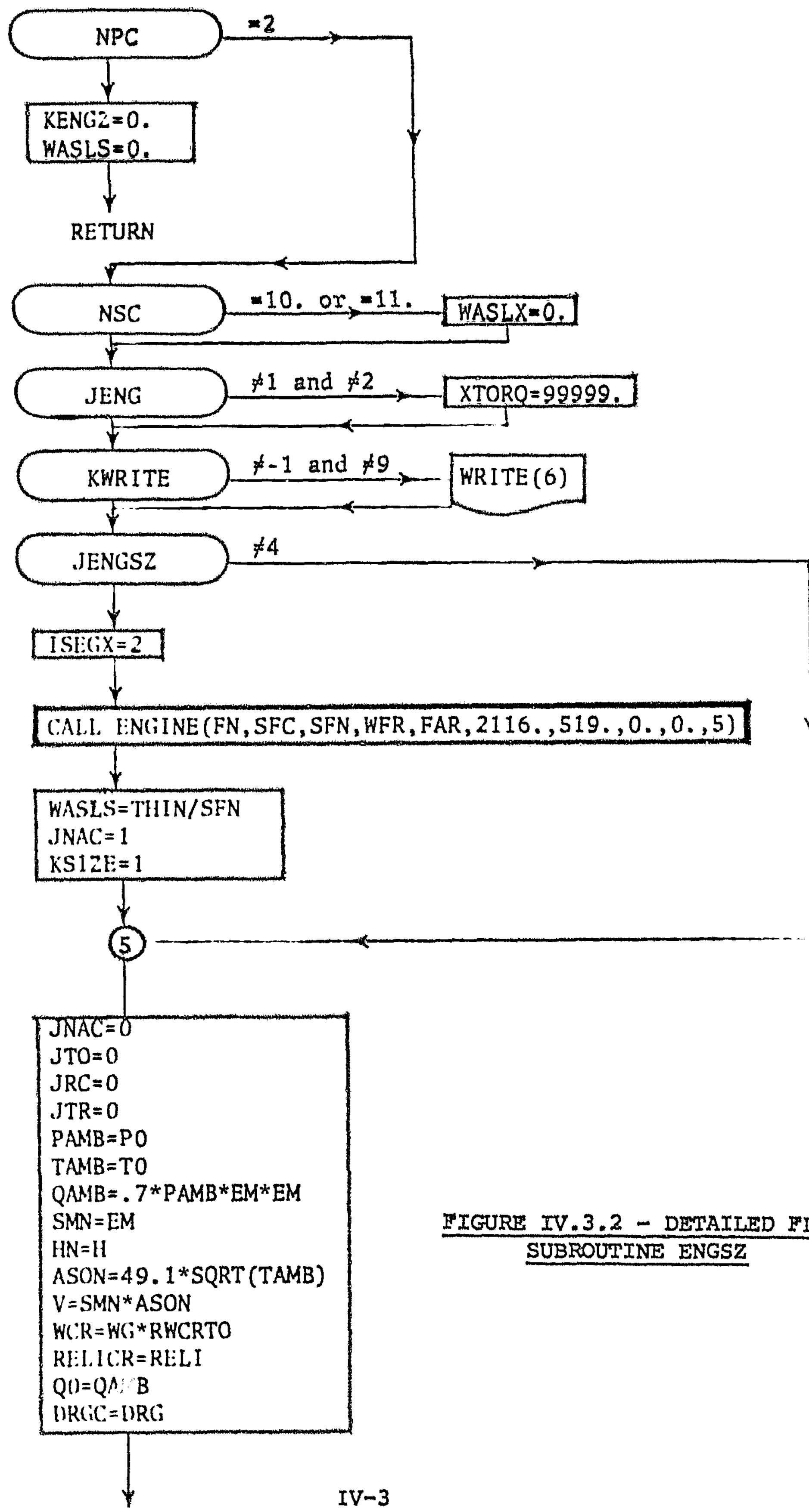
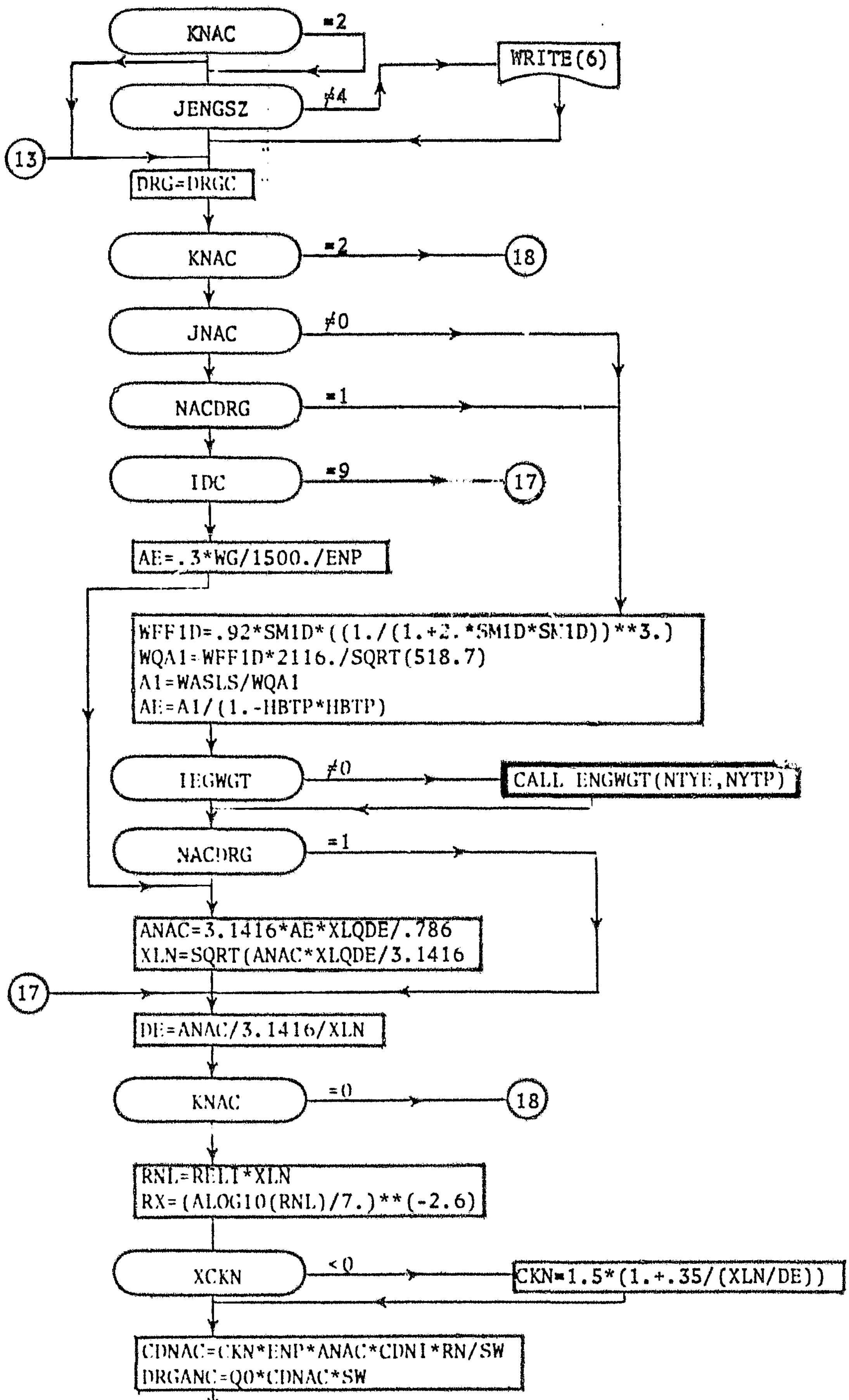
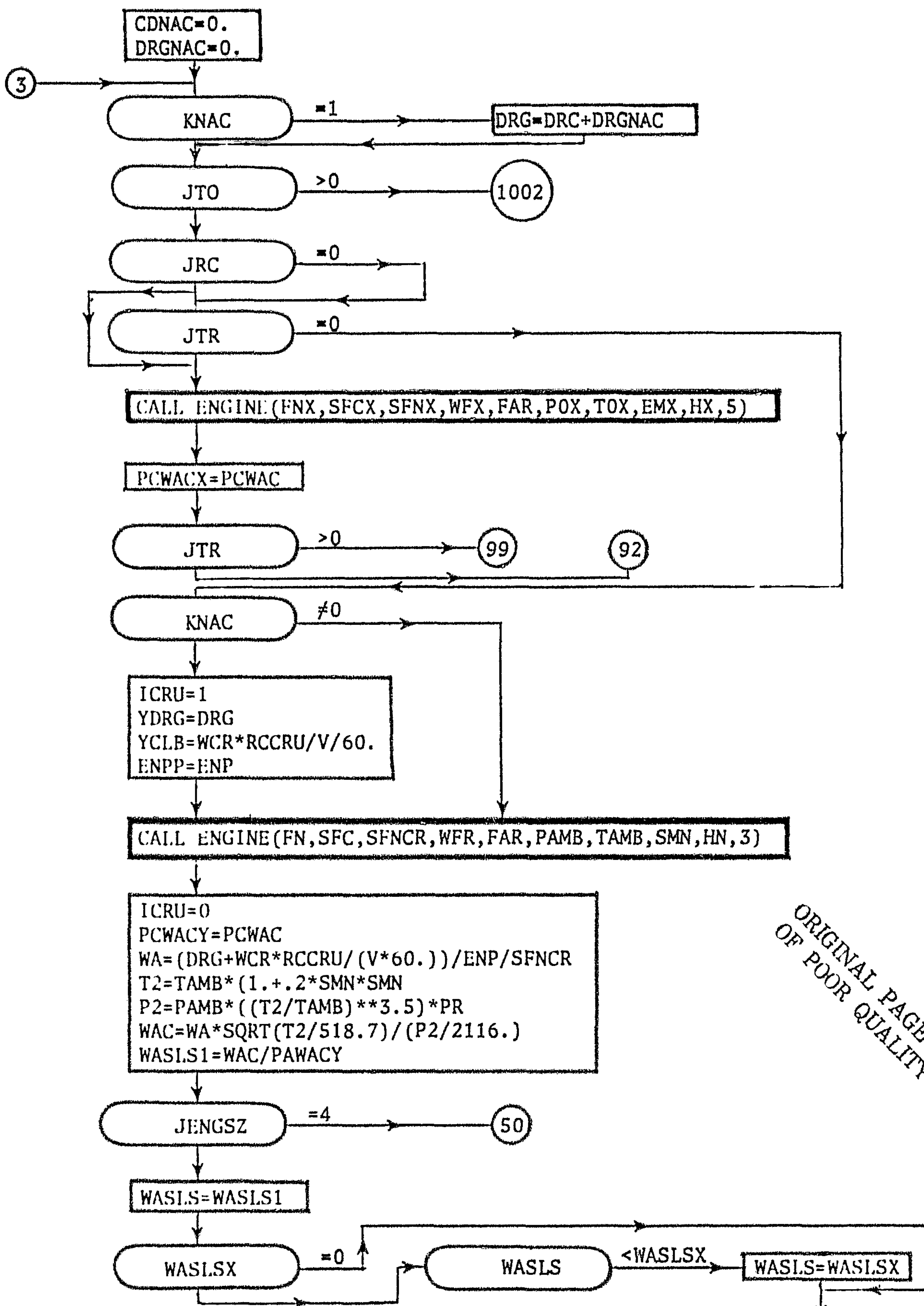
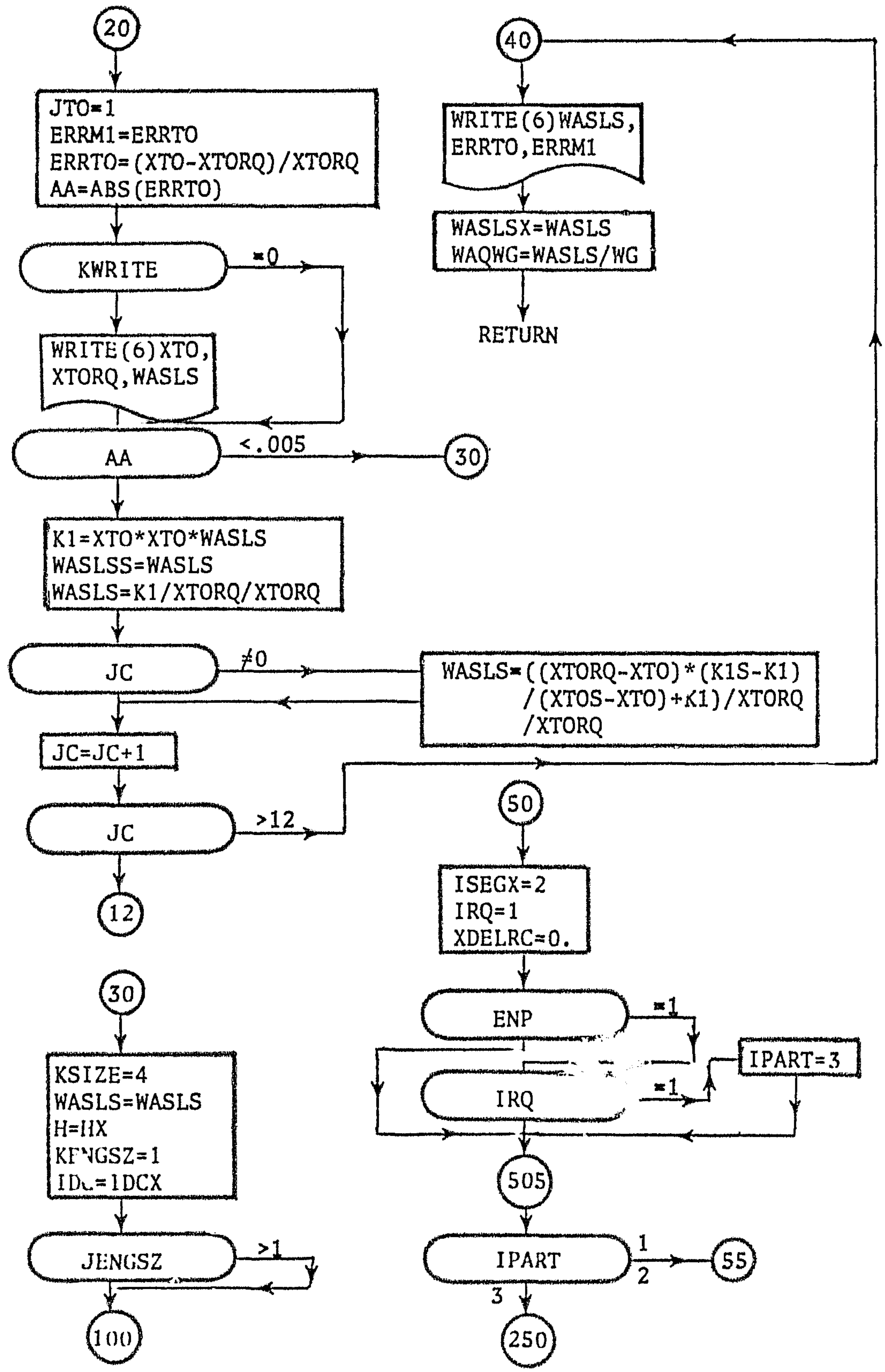


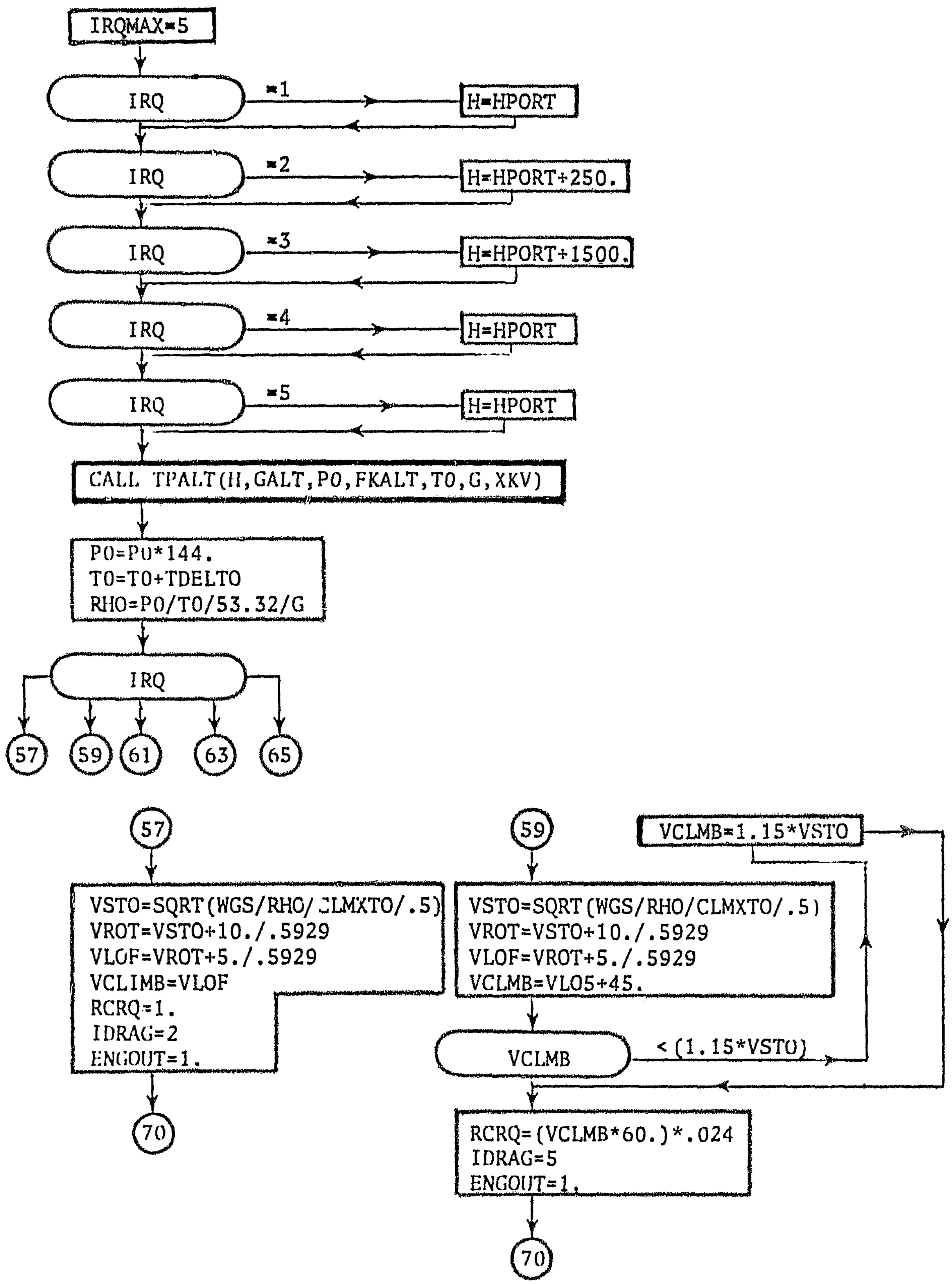
FIGURE IV.3.2 - DETAILED FLOWCHART, SUBROUTINE ENGSZ

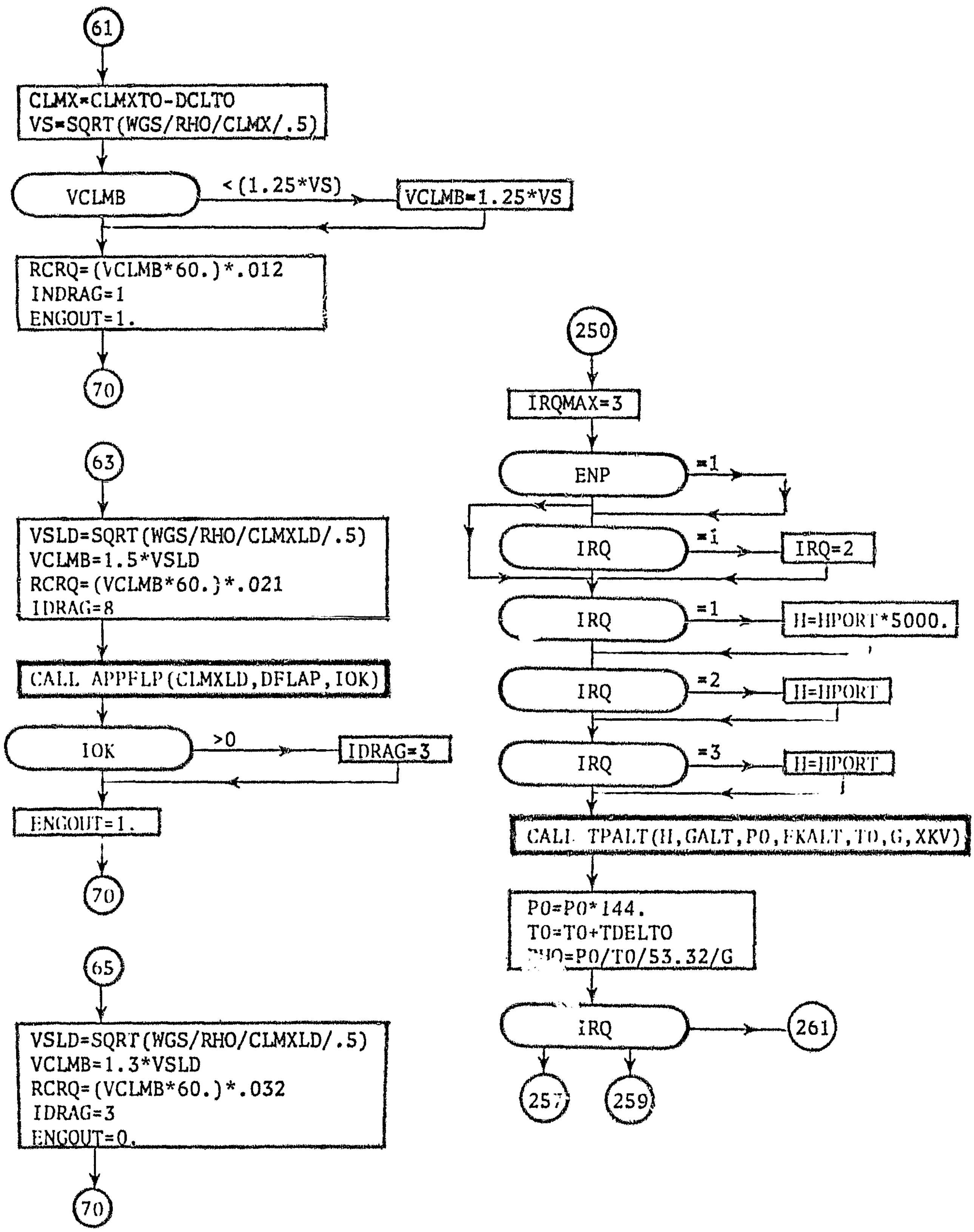

KNAC
=2
JENGSZ
≠4
WRITE(6)
13
DRG=DRGC
KNAC
=2
18
JNAC
≠0
NACDRG
=1
IDC
=9
17
AE=.3*WG/1500./ENP
WFF1D=.92*SM1D*((1./(1.+2.*SM1D*SM1D))**3.)
WQA1=WFF1D*2116./SQRT(518.7)
A1=WASLS/WQA1
AE=A1/(1.-HBTP*HBTP)
IEGWGT
≠0
CALL ENGWGT(NTYE,NYTP)
NACDRG
=1
ANAC=3.1416*AE*XLQDE/.786
XLN=SQRT(ANAC*XLQDE/3.1416
17
DE=ANAC/3.1416/XLN
KNAC
=0
18
RNL=RELT*XLN
RX=(ALOG10(RNL)/7.)**(-2.6)
XCKN
<0
CKN=1.5*(1.+.35/(XLN/DE))
CDNAC=CKN*ENP*ANAC*CDNI*RN/SW
DRGANC=QO*CDNAC*SW

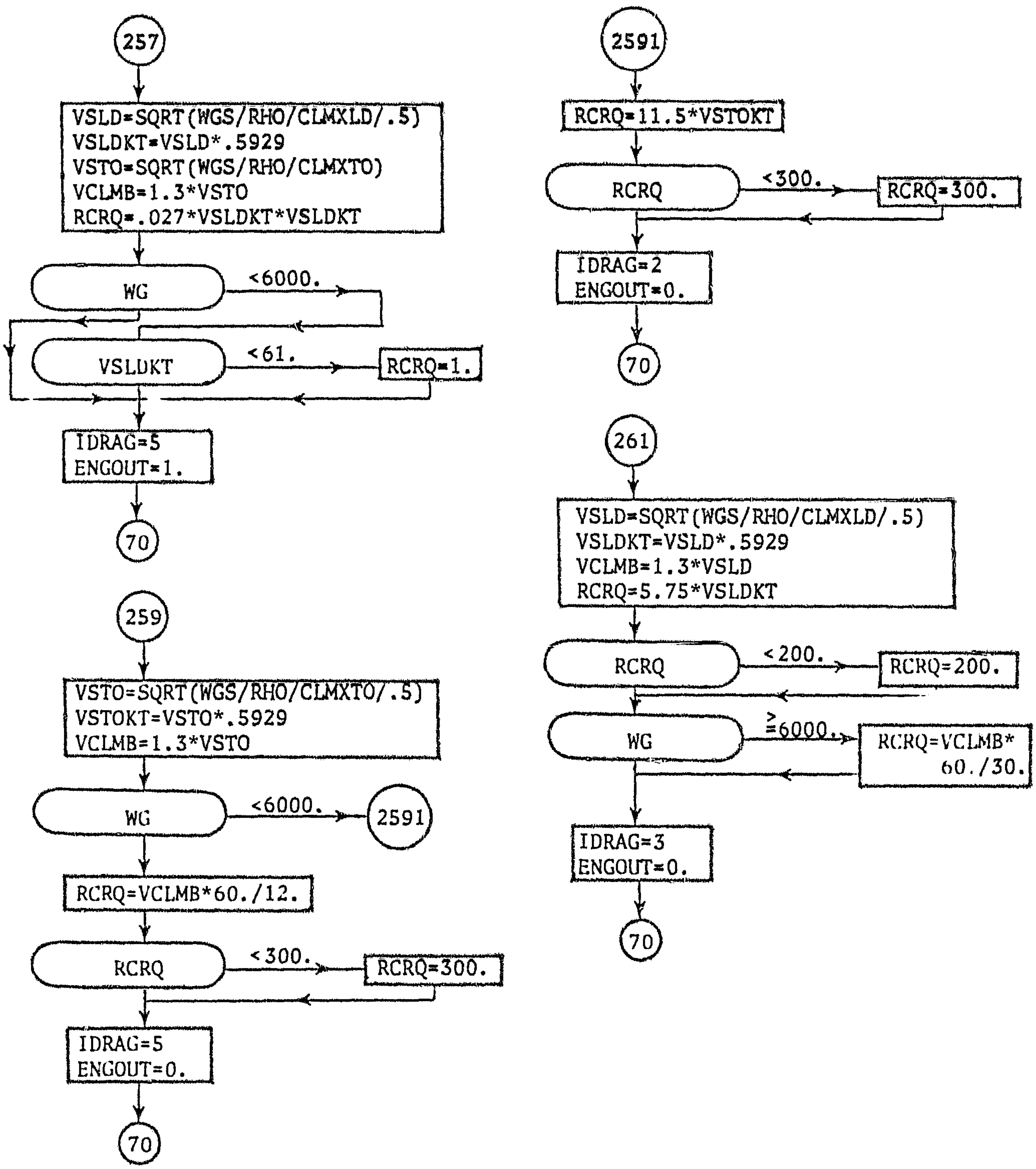

CDNAC=0.
DRGNAC=0.
3
KNAC
=1
DRG=DRC+DRGNAC
JTO
>0
1002
JRC
=0
JTR
=0
CALL ENGINE(FNX,SFCX,SFNX,WFX,FAR,POX,TOX,EMX,HX,5)
PCWACX=PCWAC
JTR
>0
99
92
KNAC
≠0
ICRU=1
YDRG=DRG
YCLB=WCR*RCCRU/V/60.
ENPP=ENP
CALL ENGINE(FN,SFC,SFNCR,WFR,FAR,PAMB,TAMB,SMN,HN,3)
ICRU=0
PCWACY=PCWAC
WA=(DRG+WCR*RCCRU/(V*60.))/ENP/SFNCR
T2=TAMB*(1.+.2*SMN*SMN
P2=PAMB*((T2/TAMB)**3.5)*PR
WAC=WA*SQRT(T2/518.7)/(P2/2116.)
WASLS1=WAC/PAWACY
JENGSZ
=4
50
WASLS=WASLS1
WASLSX
=0
WASLS
<WASLSX
WASLS=WASLSX

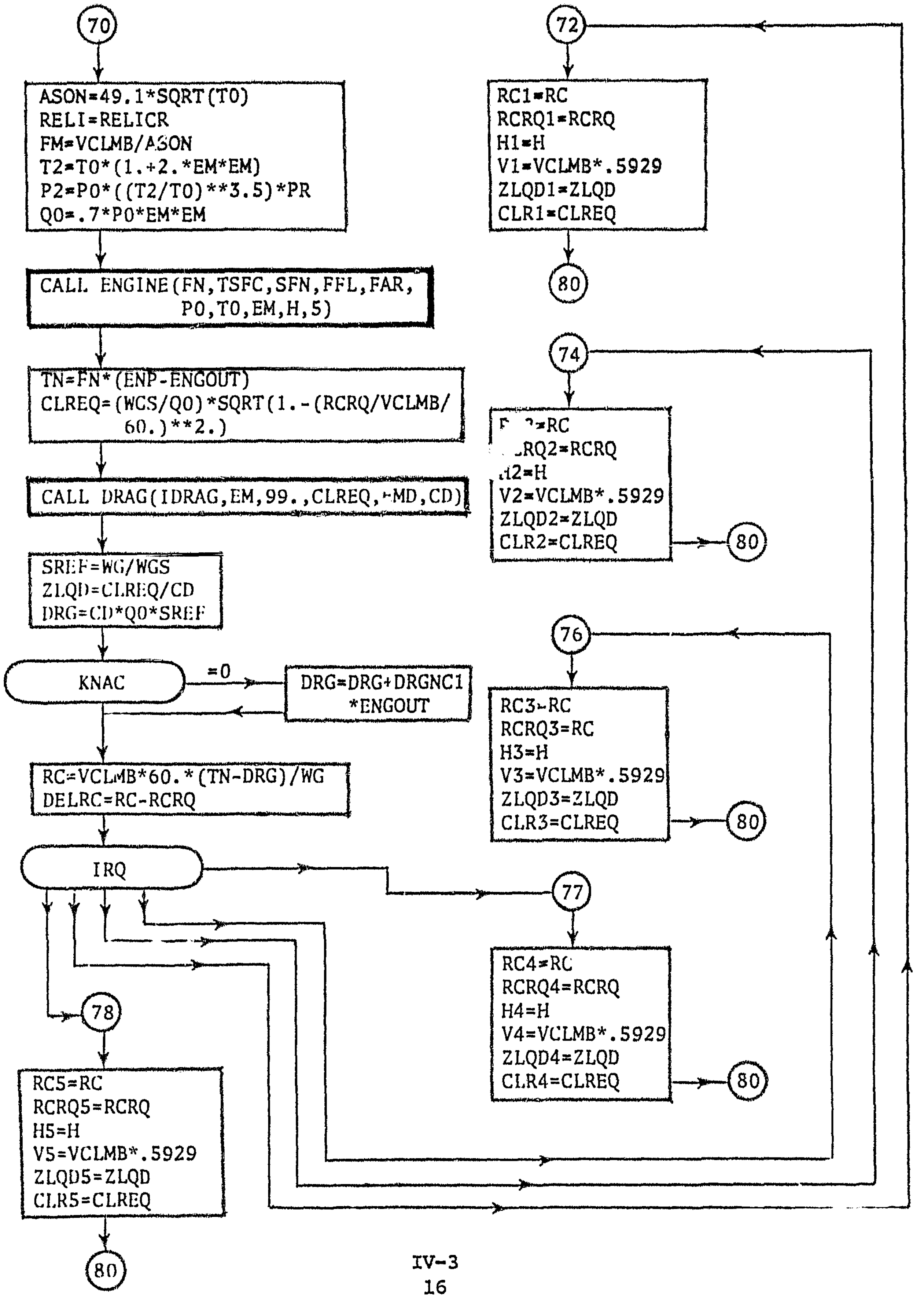


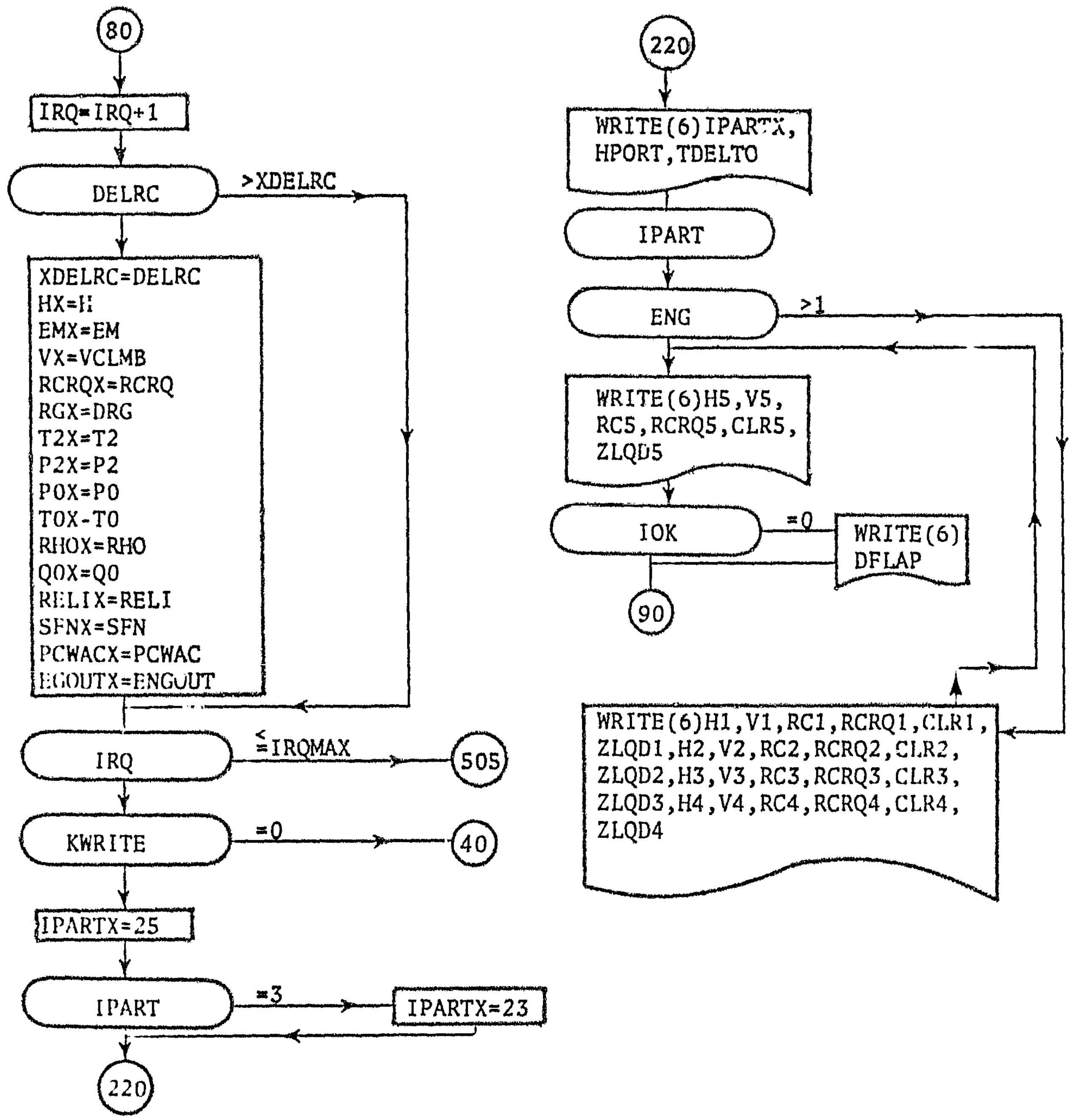
PRECEDING PAGES BLANK NOT FILMED

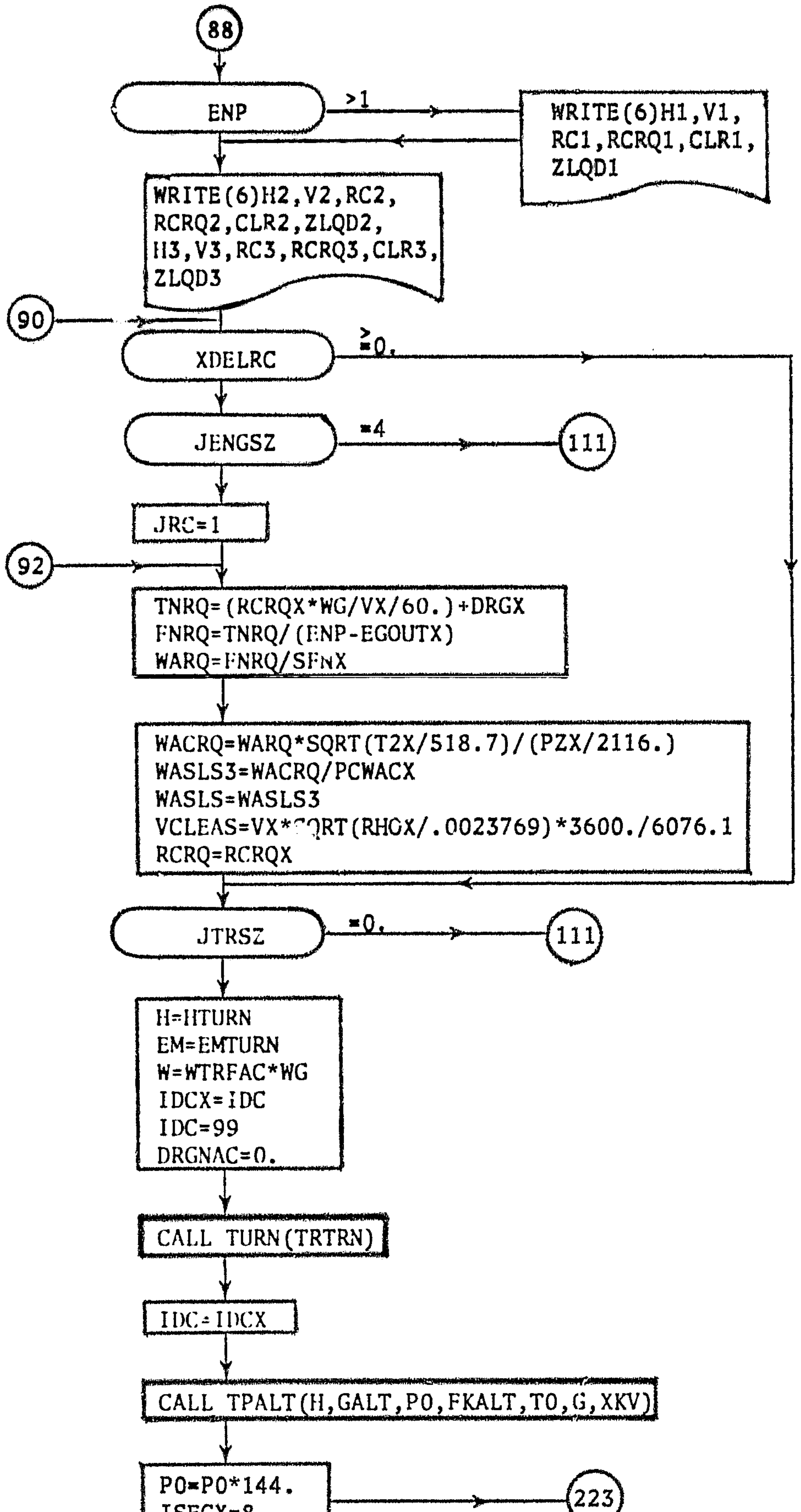

IRQMAX=5
IRQ
=1
H=HPORT
IRQ
=2
H=HPORT+250.
IRQ
=3
H=HPORT+1500.
IRQ
=4
H=HPORT
IRQ
=5
H=HPORT
CALL TPALT(H,GALT,P0,FKALT,T0,G,XKV)
P0=P0*144.
T0=T0+TDELTO
RHO=P0/T0/53.32/G
IRQ
57
59
61
63
65
57
VSTO=SQRT(WGS/RHO/CLMXTO/.5)
VROT=VSTO+10./.5929
VLOF=VROT+5./.5929
VCLIMB=VLOF
RCRQ=1.
IDRAG=2
ENGOUT=1.
70
59
VCLMB=1.15*VSTO
VSTO=SQRT(WGS/RHO/CLMXTO/.5)
VROT=VSTO+10./.5929
VLOF=VROT+5./.5929
VCLMB=VLO5+45.
VCLMB
< (1.15*VSTO)
RCRQ=(VCLMB*60.)*.024
IDRAG=5
ENGOUT=1.
70

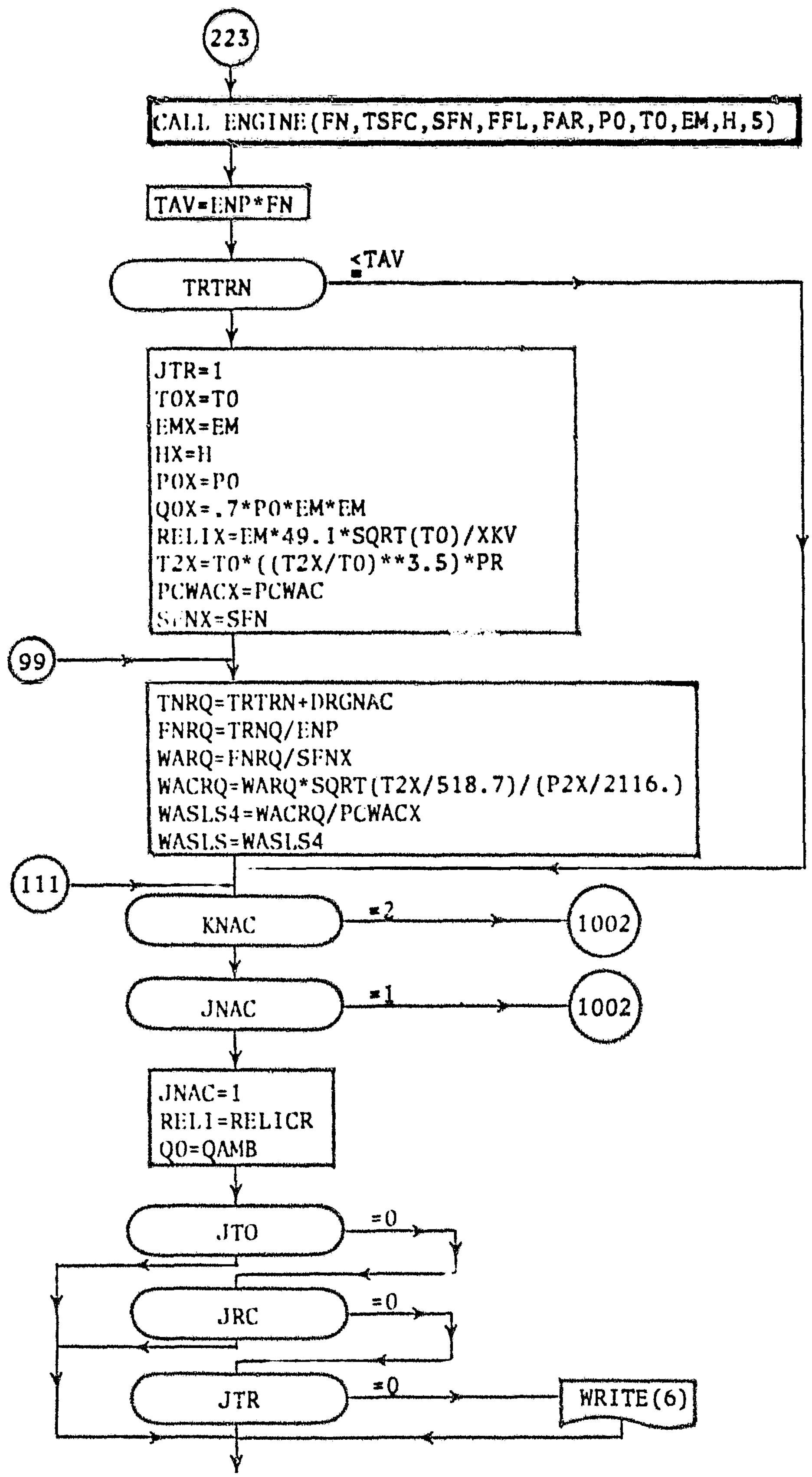

61
CLMX=CLMXTO-DCLTO
VS=SQRT(WGS/RHO/CLMX/.5)
VCLMB
<(1.25*VS)
VCLMB=1.25*VS
RCRQ=(VCLMB*60.)*.012
INDRAG=1
ENGOUT=1.
70
63
VSLD=SQRT(WGS/RHO/CLMXLD/.5)
VCLMB=1.5*VSLD
RCRQ=(VCLMB*60.)*.021
IDRAG=8
CALL APPFLP(CLMXLD,DFLAP,IOK)
IOK
>0
IDRAG=3
ENGOUT=1.
70
65
VSLD=SQRT(WGS/RHO/CLMXLD/.5)
VCLMB=1.3*VSLD
RCRQ=(VCLMB*60.)*.032
IDRAG=3
ENGOUT=0.
70
250
IRQMAX=3
ENP
=1
IRQ
=1
IRQ=2
IRQ
=1
H=HPORT*5000.
IRQ
=2
H=HPORT
IRQ
=3
H=HPORT
CALL TPALT(H,GALT,P0,FKALT,T0,G,XKV)
P0=P0*144.
T0=T0+TDELT0
RHO=P0/T0/53.32/G
IRQ
261
257
259

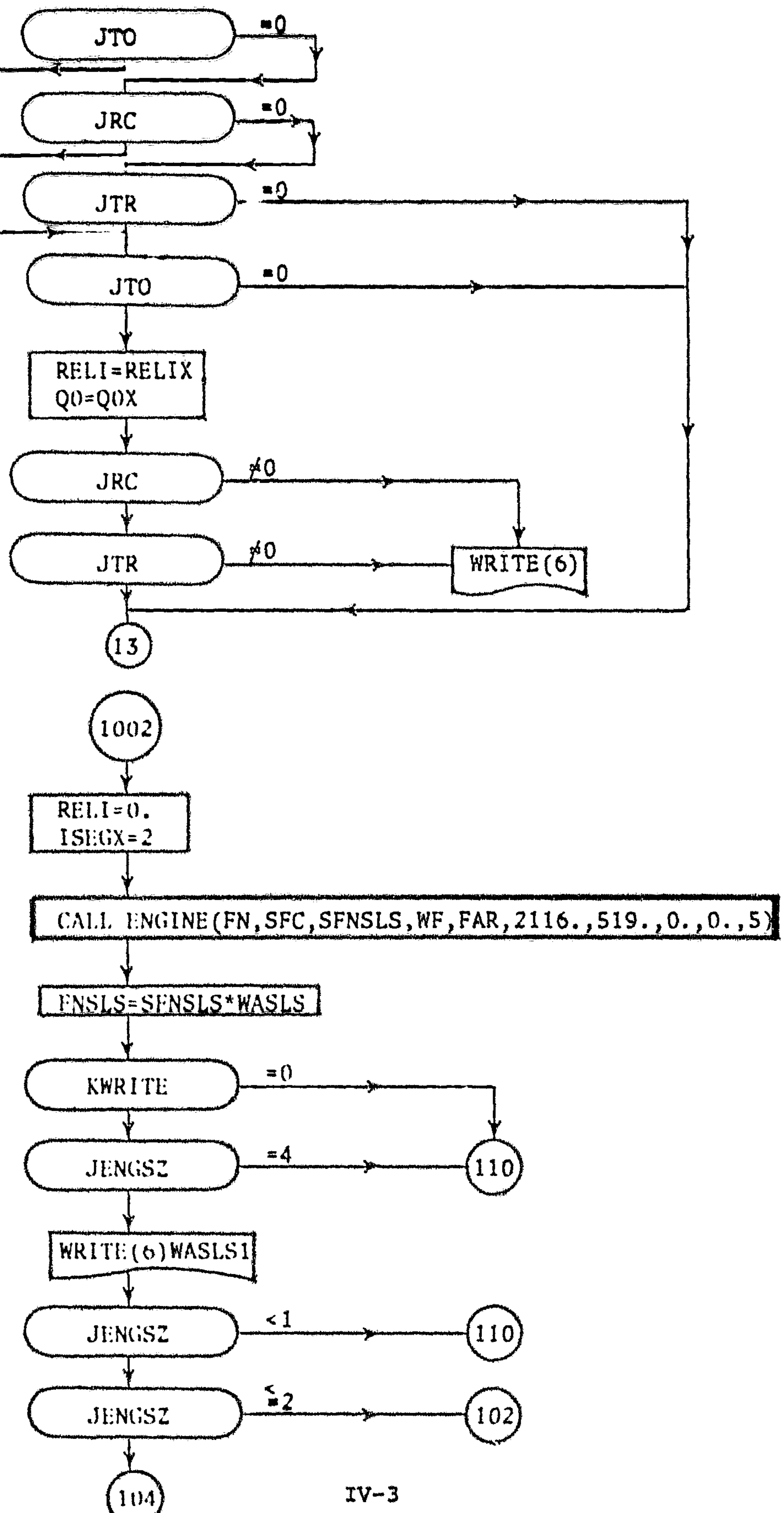

257
VSLD=SQRT(WGS/RHO/CLMXLD/.5)
VSLDKT=VSLD*.5929
VSTO=SQRT(WGS/RHO/CLMXTO)
VCLMB=1.3*VSTO
RCRQ=.027*VSLDKT*VSLDKT
WG
<6000.
VSLDKT
<61.
RCRQ=1.
IDRAG=5
ENGOUT=1.
70
259
VSTO=SQRT(WGS/RHO/CLMXTO/.5)
VSTOKT=VSTO*.5929
VCLMB=1.3*VSTO
WG
<6000.
2591
RCRQ=VCLMB*60./12.
RCRQ
<300.
RCRQ=300.
IDRAG=5
ENGOUT=0.
70
2591
RCRQ=11.5*VSTOKT
RCRQ
<300.
RCRQ=300.
IDRAG=2
ENGOUT=0.
70
261
VSLD=SQRT(WGS/RHO/CLMXLD/.5)
VSLDKT=VSLD*.5929
VCLMB=1.3*VSLD
RCRQ=5.75*VSLDKT
RCRQ
<200.
RCRQ=200.
WG
≧6000.
RCRQ=VCLMB*60./30.
IDRAG=3
ENGOUT=0.
70

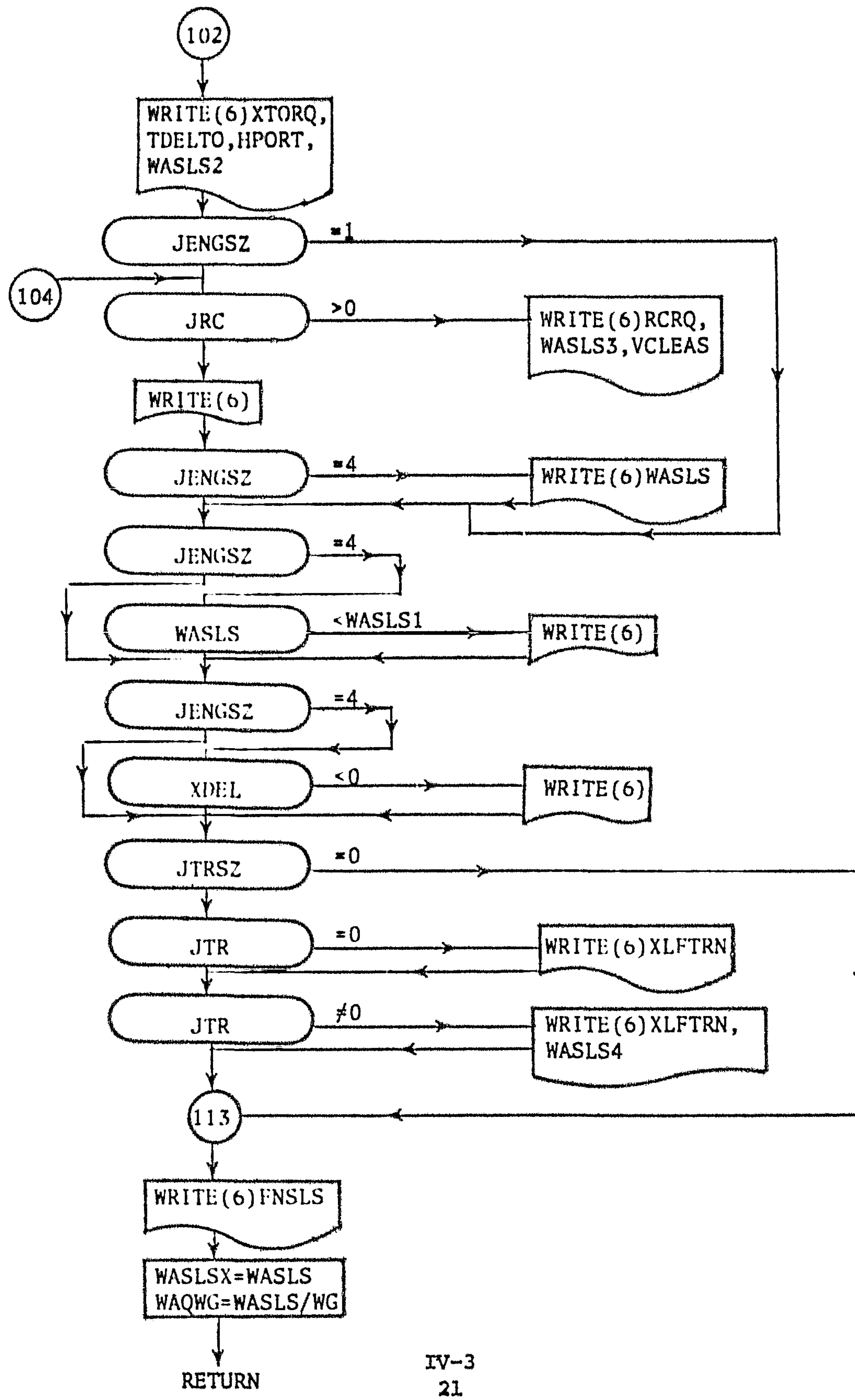

70
ASON=49.1*SQRT(T0)
RELI=RELICR
FM=VCLMB/ASON
T2=T0*(1.+2.*EM*EM)
P2=P0*((T2/T0)**3.5)*PR
Q0=.7*P0*EM*EM
CALL ENGINE(FN,TSFC,SFN,FFL,FAR, P0,T0,EM,H,5)
TN=FN*(ENP-ENGOUT)
CLREQ=(WCS/Q0)*SQRT(1.-(RCRQ/VCLMB/ 60.)**2.)
CALL DRAG(IDRAG,EM,99.,CLREQ,MD,CD)
SREF=WG/WGS
ZLQD=CLREQ/CD
DRG=CD*Q0*SREF
KNAC
=0
DRG=DRG+DRGNC1 *ENGOUT
RC=VCLMB*60.*(TN-DRG)/WG
DELRC=RC-RCRQ
IRQ
78
RC5=RC
RCRQ5=RCRQ
H5=H
V5=VCLMB*.5929
ZLQD5=ZLQD
CLR5=CLREQ
80
72
RC1=RC
RCRQ1=RCRQ
H1=H
V1=VCLMB*.5929
ZLQD1=ZLQD
CLR1=CLREQ
80
74
=RC
RQ2=RCRQ
2=H
V2=VCLMB*.5929
ZLQD2=ZLQD
CLR2=CLREQ
80
76
RC3=RC
RCRQ3=RC
H3=H
V3=VCLMB*.5929
ZLQD3=ZLQD
CLR3=CLREQ
80
77
RC4=RC
RCRQ4=RCRQ
H4=H
V4=VCLMB*.5929
ZLQD4=ZLQD
CLR4=CLREQ
80


80
IRQ=IRQ+1
DELRC
>XDELRC
XDELRC=DELRC
HX=H
EMX=EM
VX=VCLMB
RCRQX=RCRQ
RGX=DRG
T2X=T2
P2X=P2
P0X=P0
T0X-T0
RHOX=RHO
Q0X=Q0
RELIX=RELI
SFNX=SFN
PCWACX=PCWAC
EGOUTX=ENGOUT
IRQ
≦IRQMAX
505
KWRITE
=0
40
IPARTX=25
IPART
=3
IPARTX=23
220
220
WRITE(6)IPARTX,
HPORT,TDELTO
IPART
ENG
>1
WRITE(6)H5,V5,
RC5,RCRQ5,CLR5,
ZLQD5
IOK
=0
WRITE(6)
DFLAP
90
WRITE(6)H1,V1,RC1,RCRQ1,CLR1,
ZLQD1,H2,V2,RC2,RCRQ2,CLR2,
ZLQD2,H3,V3,RC3,RCRQ3,CLR3,
ZLQD3,H4,V4,RC4,RCRQ4,CLR4,
ZLQD4


88
ENP
>1
WRITE(6)H1,V1,
RC1,RCRQ1,CLR1,
ZLQD1
WRITE(6)H2,V2,RC2,
RCRQ2,CLR2,ZLQD2,
H3,V3,RC3,RCRQ3,CLR3,
ZLQD3
90
XDELRC
≥0.
JENGSZ
=4
111
JRC=1
92
TNRQ=(RCRQX*WG/VX/60.)+DRGX
FNRQ=TNRQ/(ENP-EGOUTX)
WARQ=FNRQ/SFNX
WACRQ=WARQ*SQRT(T2X/518.7)/(PZX/2116.)
WASLS3=WACRQ/PCWACX
WASLS=WASLS3
VCLEAS=VX*SQRT(RHOX/.0023769)*3600./6076.1
RCRQ=RCRQX
JTRSZ
=0.
111
H=HTURN
EM=EMTURN
W=WTRFAC*WG
IDCX=IDC
IDC=99
DRGNAC=0.
CALL TURN(TRTRN)
IDC=IDCX
CALL TPALT(H,GALT,P0,FKALT,T0,G,XKV)
P0=P0*144.
ISEGX=8
223


223
CALL ENGINE(FN,TSFC,SFN,FFL,FAR,P0,T0,EM,H,5)
TAV=ENP*FN
TRTRN
≤TAV
JTR=1
TOX=T0
EMX=EM
HX=H
POX=P0
QOX=.7*P0*EM*EM
RELIX=EM*49.1*SQRT(T0)/XKV
T2X=T0*((T2X/T0)**3.5)*PR
PCWACX=PCWAC
SFNX=SFN
99
TNRQ=TRTRN+DRGNAC
FNRQ=TRNQ/ENP
WARQ=FNRQ/SFNX
WACRQ=WARQ*SQRT(T2X/518.7)/(P2X/2116.)
WASLS4=WACRQ/PCWACX
WASLS=WASLS4
111
KNAC
=2
1002
JNAC
=1
1002
JNAC=1
RELI=RELICR
Q0=QAMB
JTO
=0
JRC
=0
JTR
=0
WRITE(6)


JTO
=0
JRC
=0
JTR
=0
JTO
=0
RELI=RELIX
Q0=Q0X
JRC
≠0
JTR
≠0
WRITE(6)
13
1002
RELI=0.
ISEGX=2
CALL ENGINE(FN,SFC,SFNSLS,WF,FAR,2116.,519.,0.,0.,5)
FNSLS=SFNSLS*WASLS
KWRITE
=0
JENGSZ
=4
110
WRITE(6)WASLS1
JENGSZ
<1
110
JENGSZ
≤2
102
104


102
WRITE(6)XTORQ, TDELTO,HPORT, WASLS2
JENGSZ
=1
104
JRC
>0
WRITE(6)RCRQ, WASLS3,VCLEAS
WRITE(6)
JENGSZ
=4
WRITE(6)WASLS
JENGSZ
=4
WASLS
<WASLS1
WRITE(6)
JENGSZ
=4
XDEL
<0
WRITE(6)
JTRSZ
=0
JTR
=0
WRITE(6)XLFTRN
JTR
≠0
WRITE(6)XLFTRN, WASLS4
113
WRITE(6)FNSLS
WASLSX=WASLS
WAQWG=WASLS/WG
RETURN

IV.3.1.3 Subroutine NACDG, Nacelle Losses. Subroutine NACDG computes nacelle losses during engine sizing and performance calculations. The methodology is discussed in Section IV.1.1.3. A detailed flowchart for subroutine NACDG is presented in Figure IV.3.3. No other subroutines are called by NACDG.

NACDG

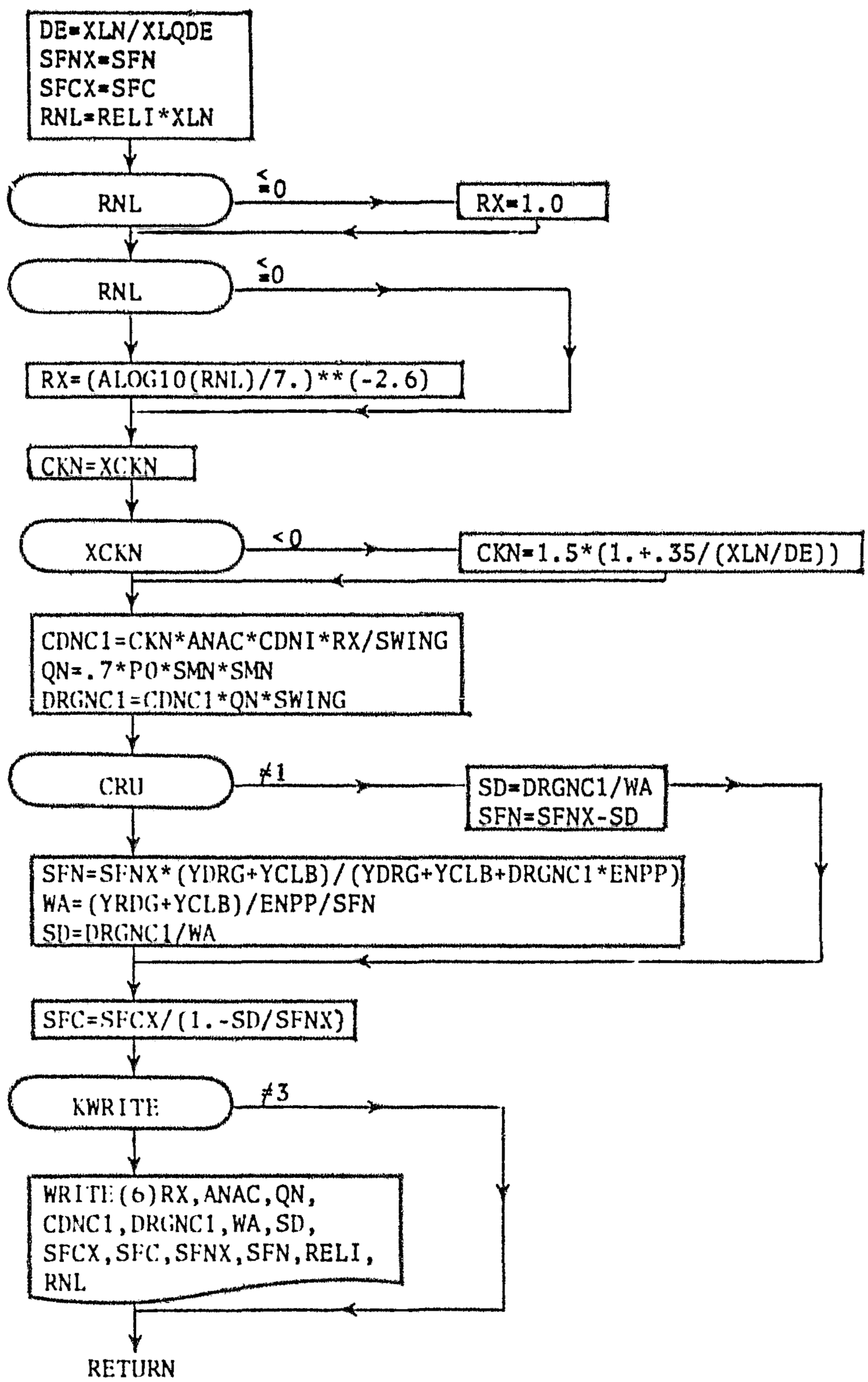


FIGURE IV.3.3 - DETAILED FLOWCHART SUBROUTINE NACDG

IV.3.2 Propeller Driven Engine Routines

IV.3.2.1 Subroutine ENGINE, Propeller Driven Engine Performance at Specified Flight Condition. This routine computes piston engine, rotary combustion engine, or gas turbine engine performance when matched to a specified propeller. Methodology is discussed in Section IV.1.2.2. Engine sizing options are exercised through the indicators KENG and KODE. The indicator NTYE controls engine type selection by calling either subroutine PWRPLT, (Section IV.1.2.3), for piston engine performance or subroutine TURBEG (Section IV.1.2.4), for turboprop engine performance. Atmospheric properties are obtained from subroutine TPALT (Section I.1.3.15). Propeller characteristics are determined through subroutine ENGDAT (Section IV.1.3). A variety of utility subroutines are called in the engine performance calculations including BIV (Section I.1.3.4), MAXMHW, (Section I.1.3.11), ITRMHW, (Section I.1.3.8), and MAXBND, (Section I.1.3.10).

A detailed flow chart for subroutine ENGINE is provided in Figure IV.3.4.

ENGINE

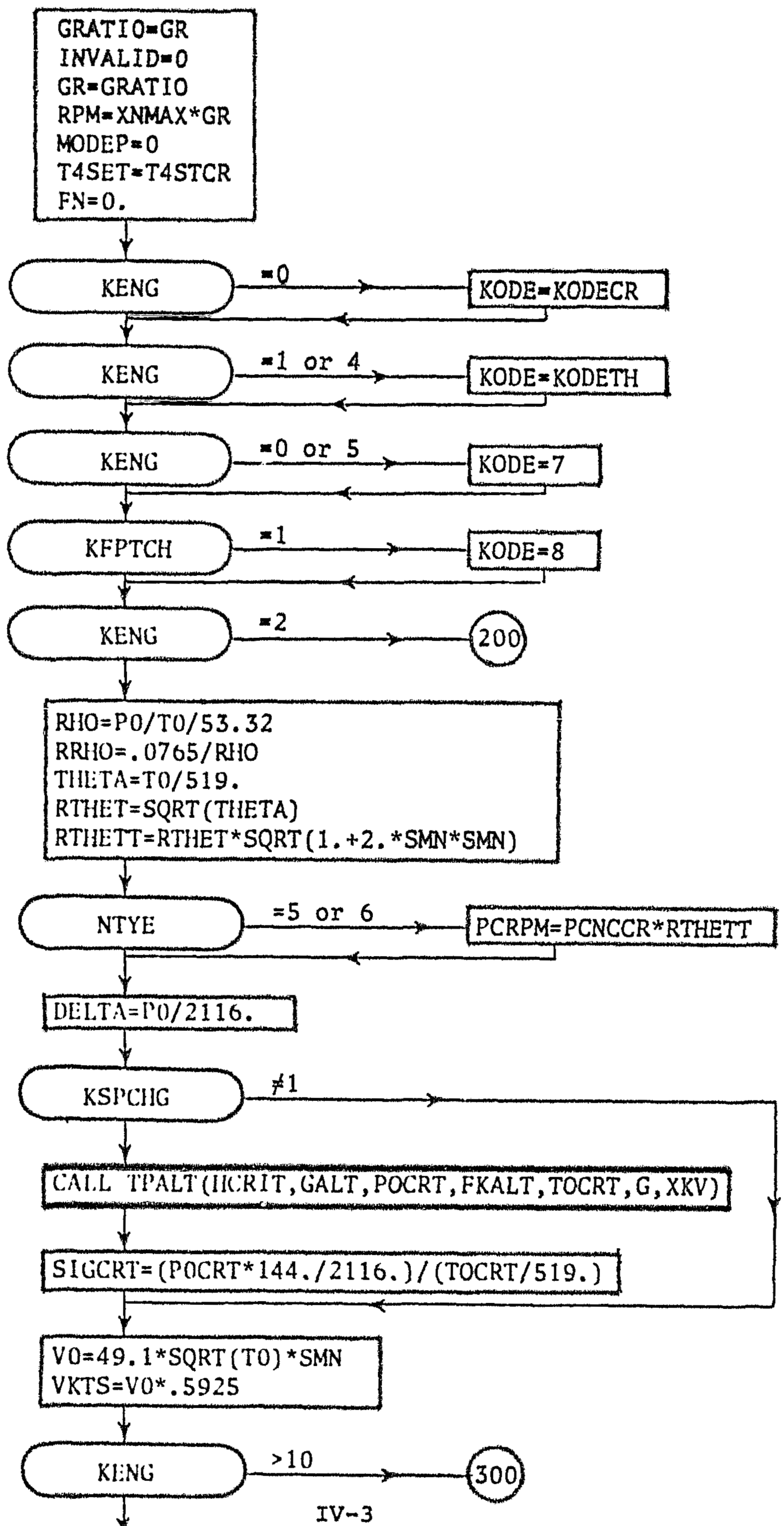
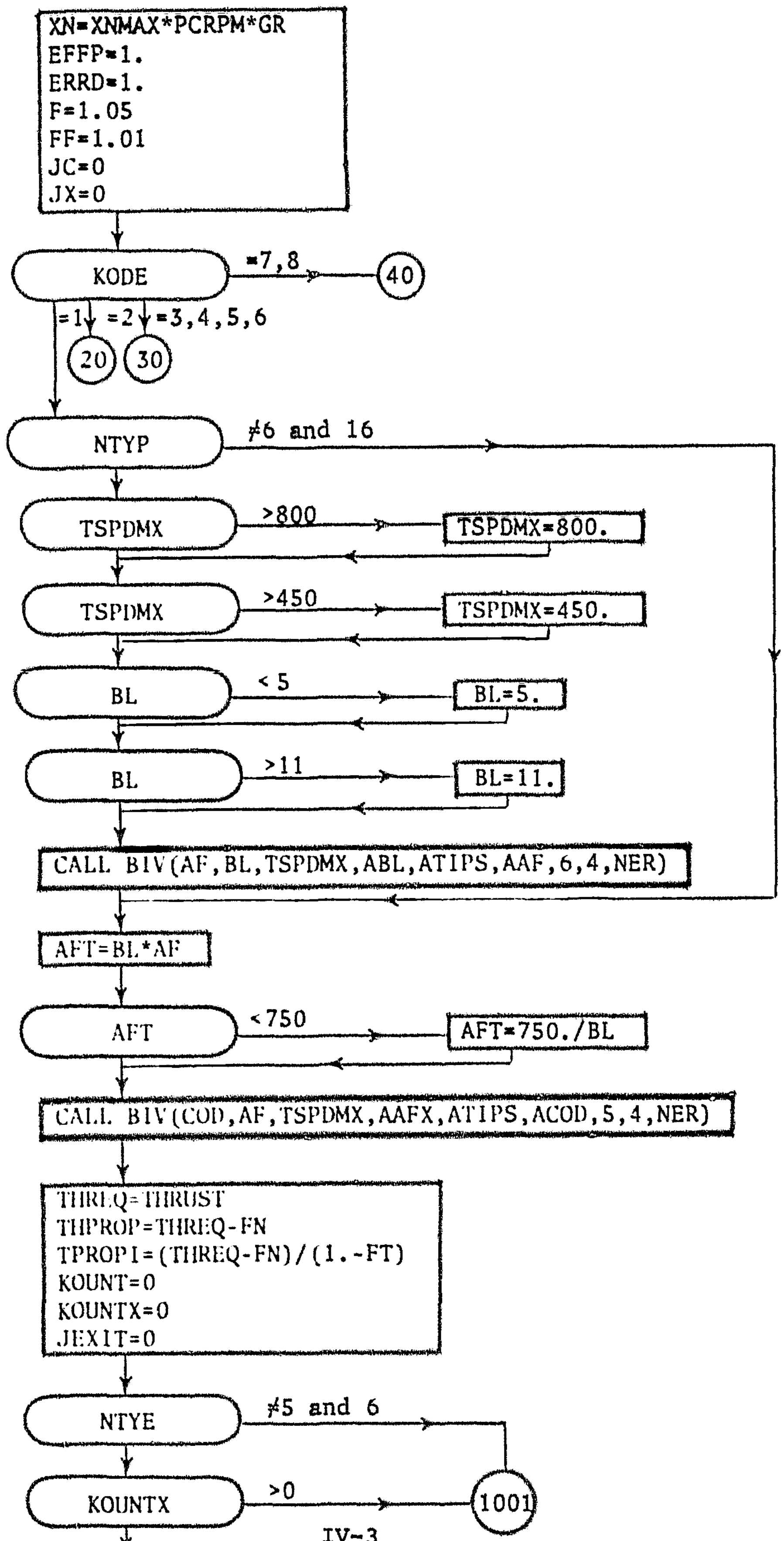
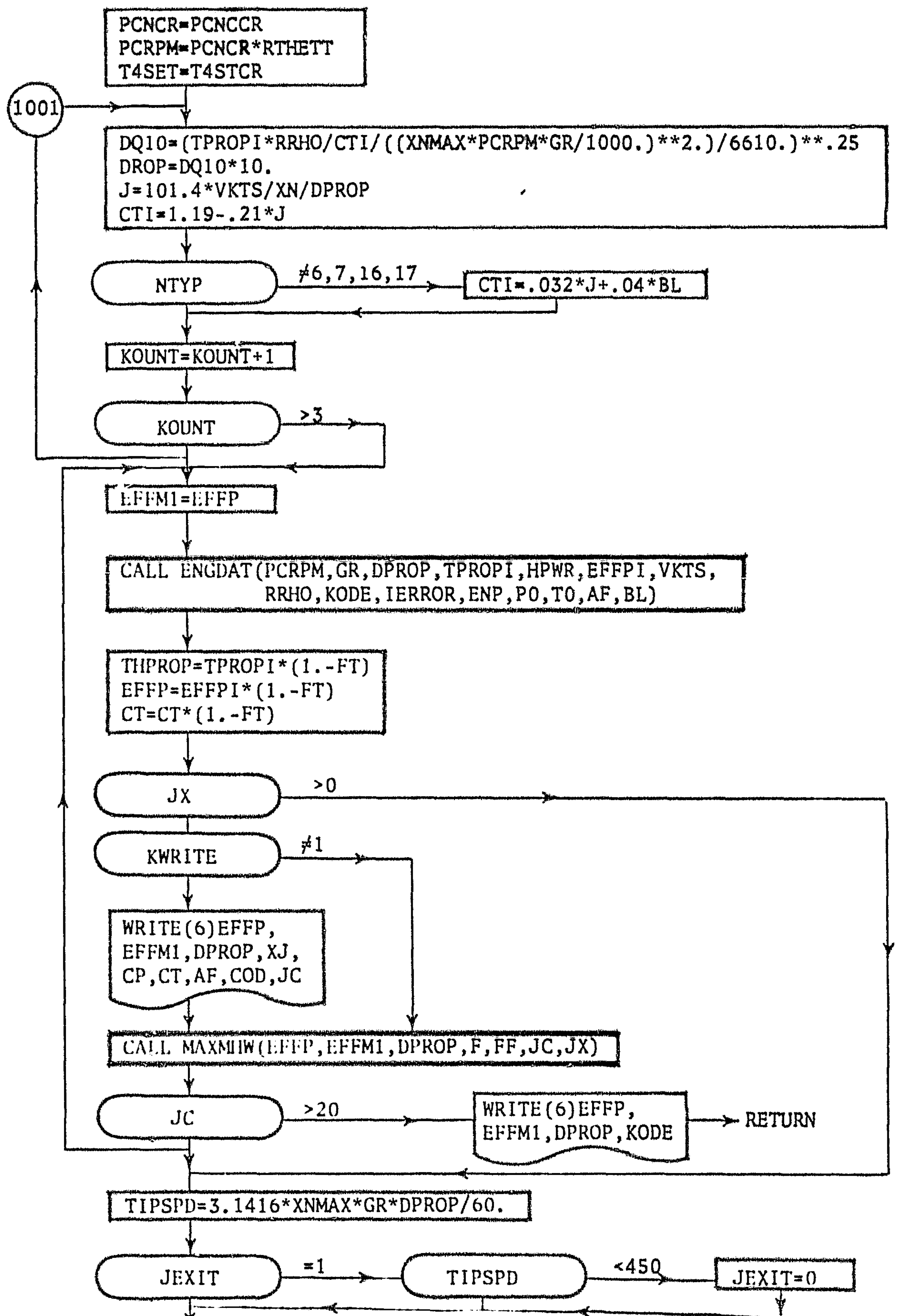
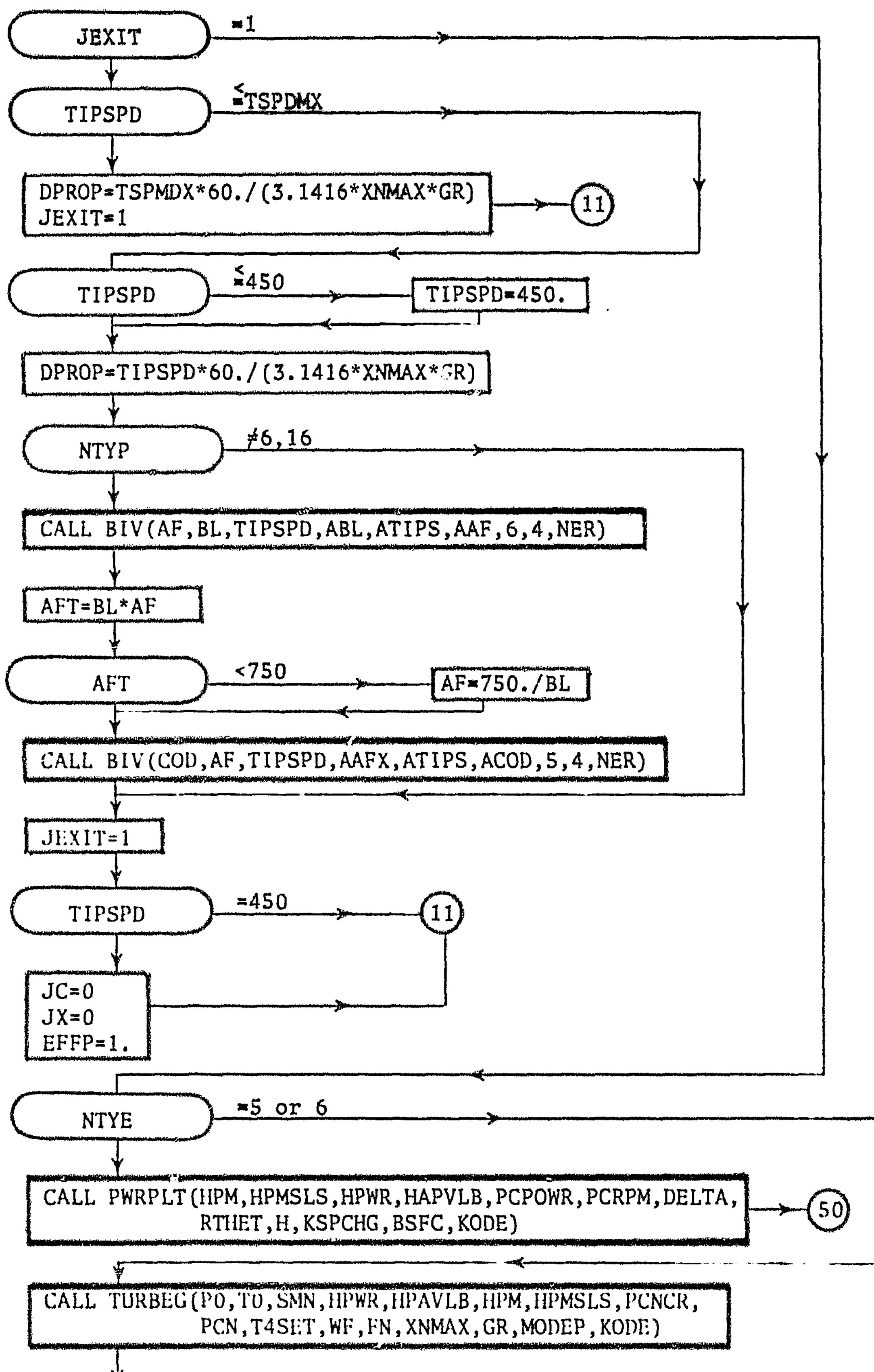
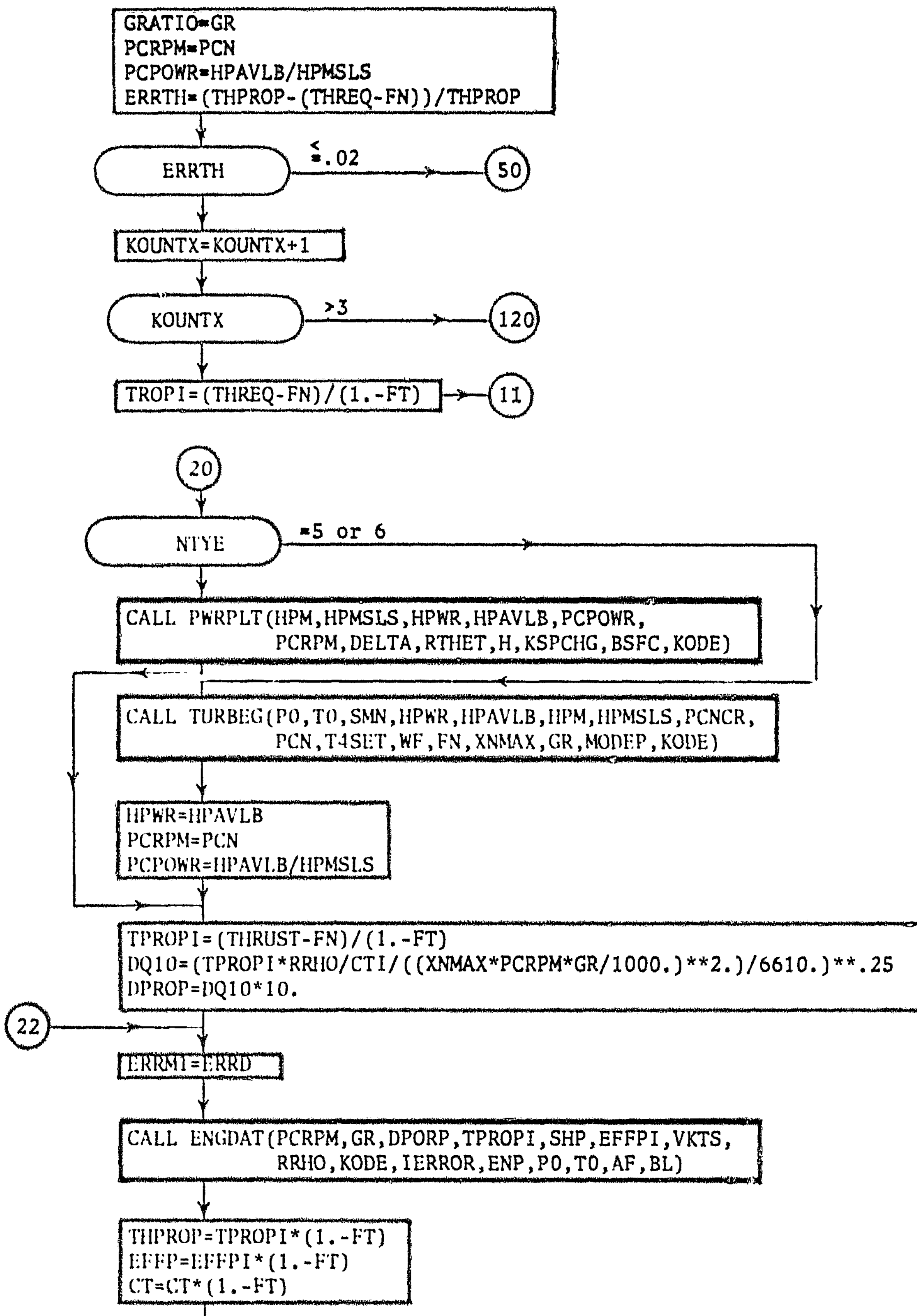


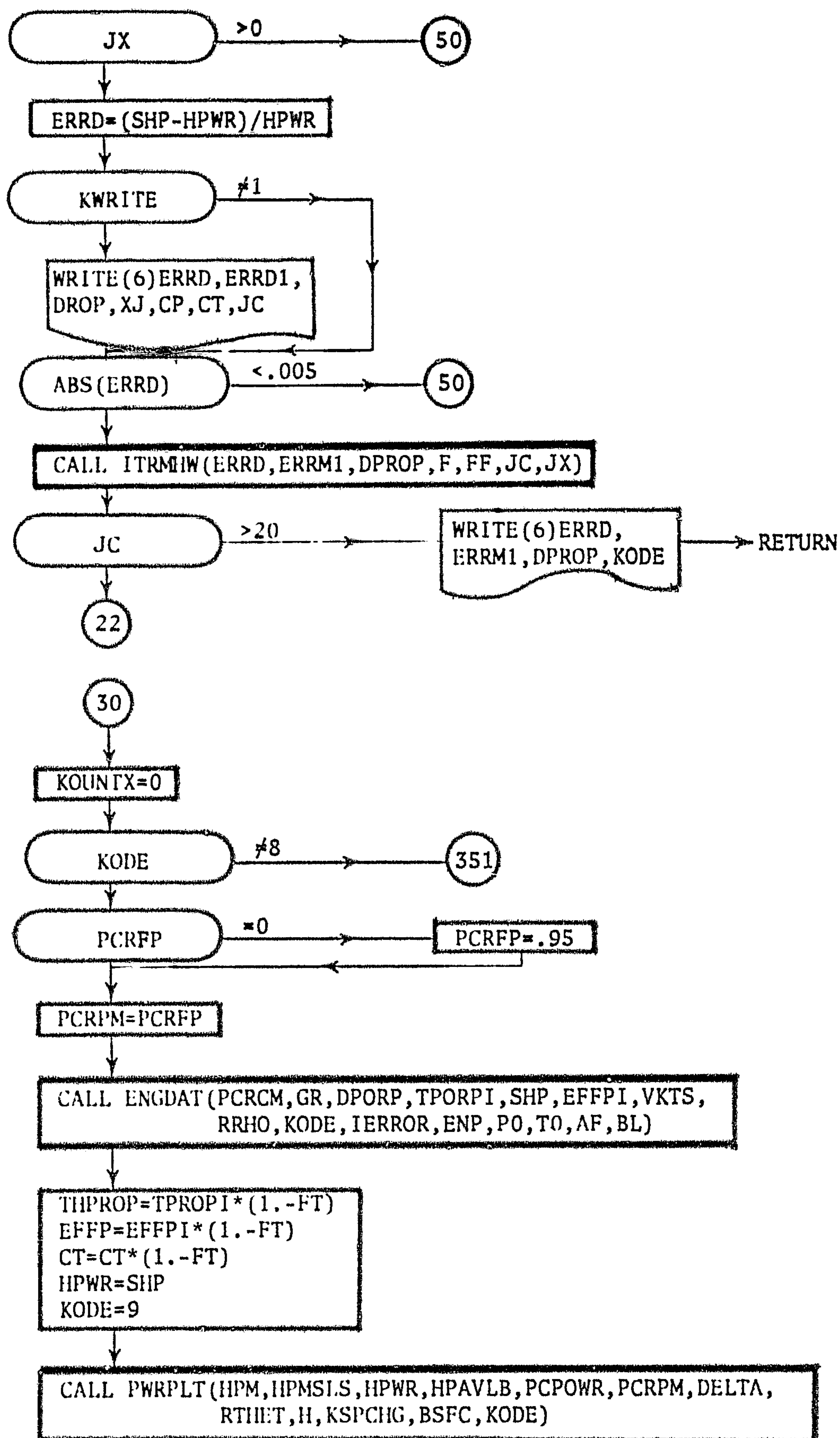
FIGURE IV.3.4 - DETAILED FLOWCHART, SUBROUTINE ENGINE(PROPELLER DRIVEN)

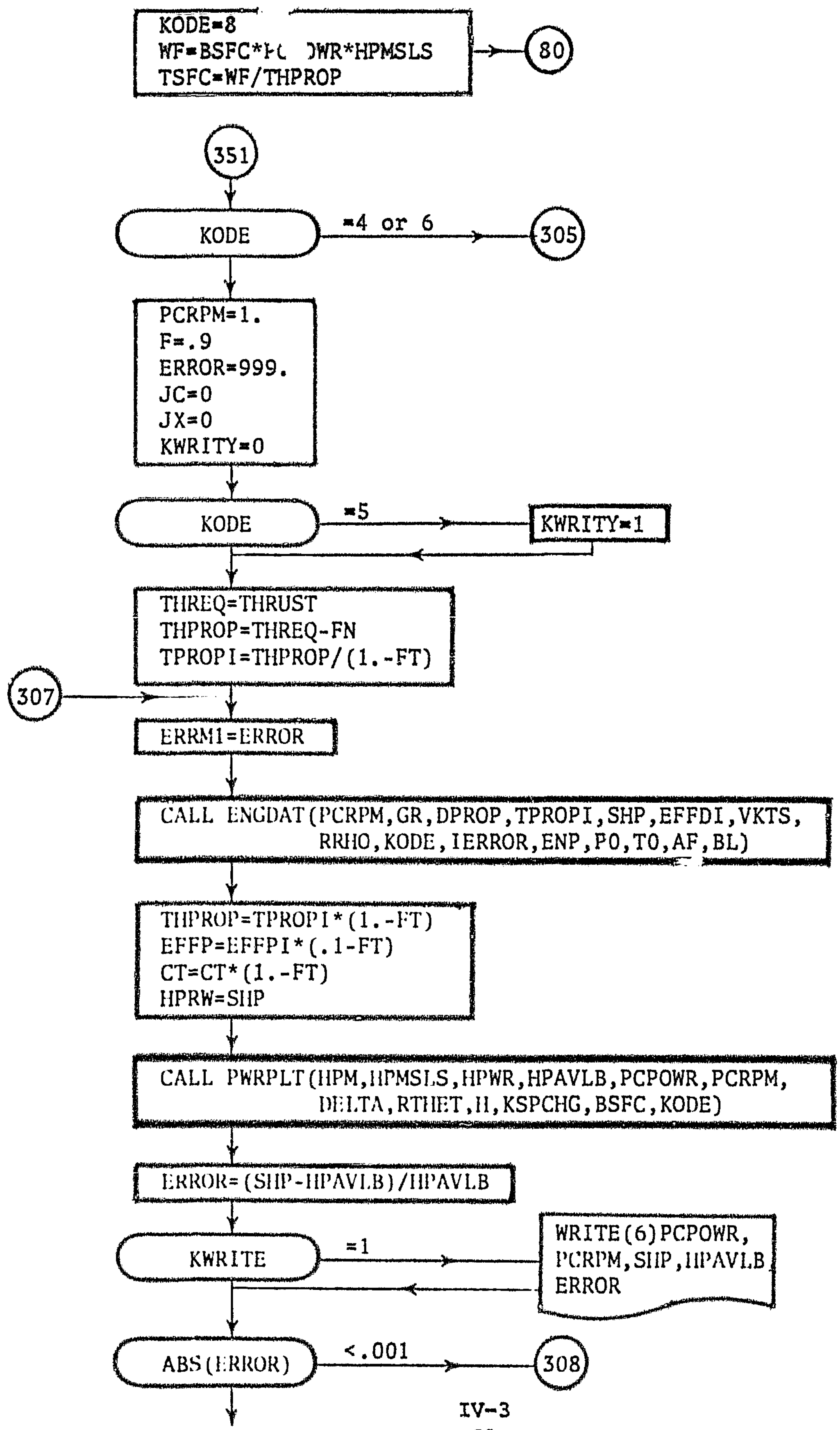

XN=XNMAX*PCRPM*GR
EFFP=1.
ERRD=1.
F=1.05
FF=1.01
JC=0
JX=0
KODE
=7,8
40
=1
=2
=3,4,5,6
20
30
NTYP
≠6 and 16
TSPDMX
>800
TSPDMX=800.
TSPDMX
>450
TSPDMX=450.
BL
< 5
BL=5.
BL
>11
BL=11.
CALL BIV(AF,BL,TSPDMX,ABL,ATIPS,AAF,6,4,NER)
AFT=BL*AF
AFT
<750
AFT=750./BL
CALL BIV(COD,AF,TSPDMX,AAFX,ATIPS,ACOD,5,4,NER)
THREQ=THRUST
THPROP=THREQ-FN
TPROPI=(THREQ-FN)/(1.-FT)
KOUNT=0
KOUNTX=0
JEXIT=0
NTYE
≠5 and 6
KOUNTX
>0
1001

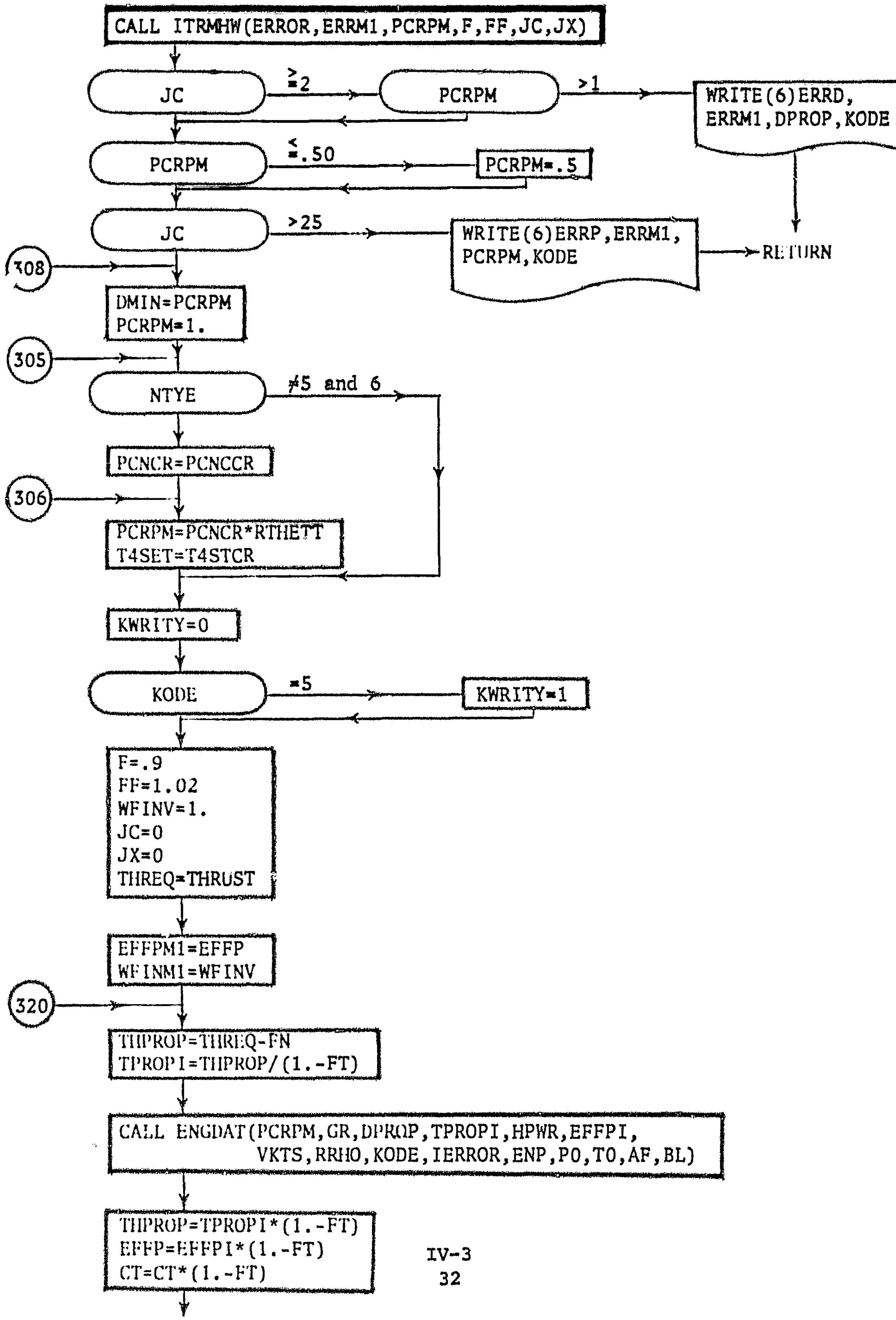

PCNCR=PCNCCR
PCRPM=PCNCR*RTHETT
T4SET=T4STCR
1001
DQ10=(TPROPI*RRHO/CTI/((XNMAX*PCRPM*GR/1000.)**2.)/6610.)**.25
DROP=DQ10*10.
J=101.4*VKTS/XN/DPROP
CTI=1.19-.21*J
NTYP
≠6,7,16,17
CTI=.032*J+.04*BL
KOUNT=KOUNT+1
KOUNT
>3
EFFM1=EFFP
CALL ENGDAT(PCRPM,GR,DPROP,TPROPI,HPWR,EFFPI,VKTS,
RRHO,KODE,IERROR,ENP,P0,T0,AF,BL)
THPROP=TPROPI*(1.-FT)
EFFP=EFFPI*(1.-FT)
CT=CT*(1.-FT)
JX
>0
KWRITE
≠1
WRITE(6)EFFP,
EFFM1,DPROP,XJ,
CP,CT,AF,COD,JC
CALL MAXMIIW(EFFP,EFFM1,DPROP,F,FF,JC,JX)
JC
>20
WRITE(6)EFFP,
EFFM1,DPROP,KODE
RETURN
TIPSPD=3.1416*XNMAX*GR*DPROP/60.
JEXIT
=1
TIPSPD
<450
JEXIT=0

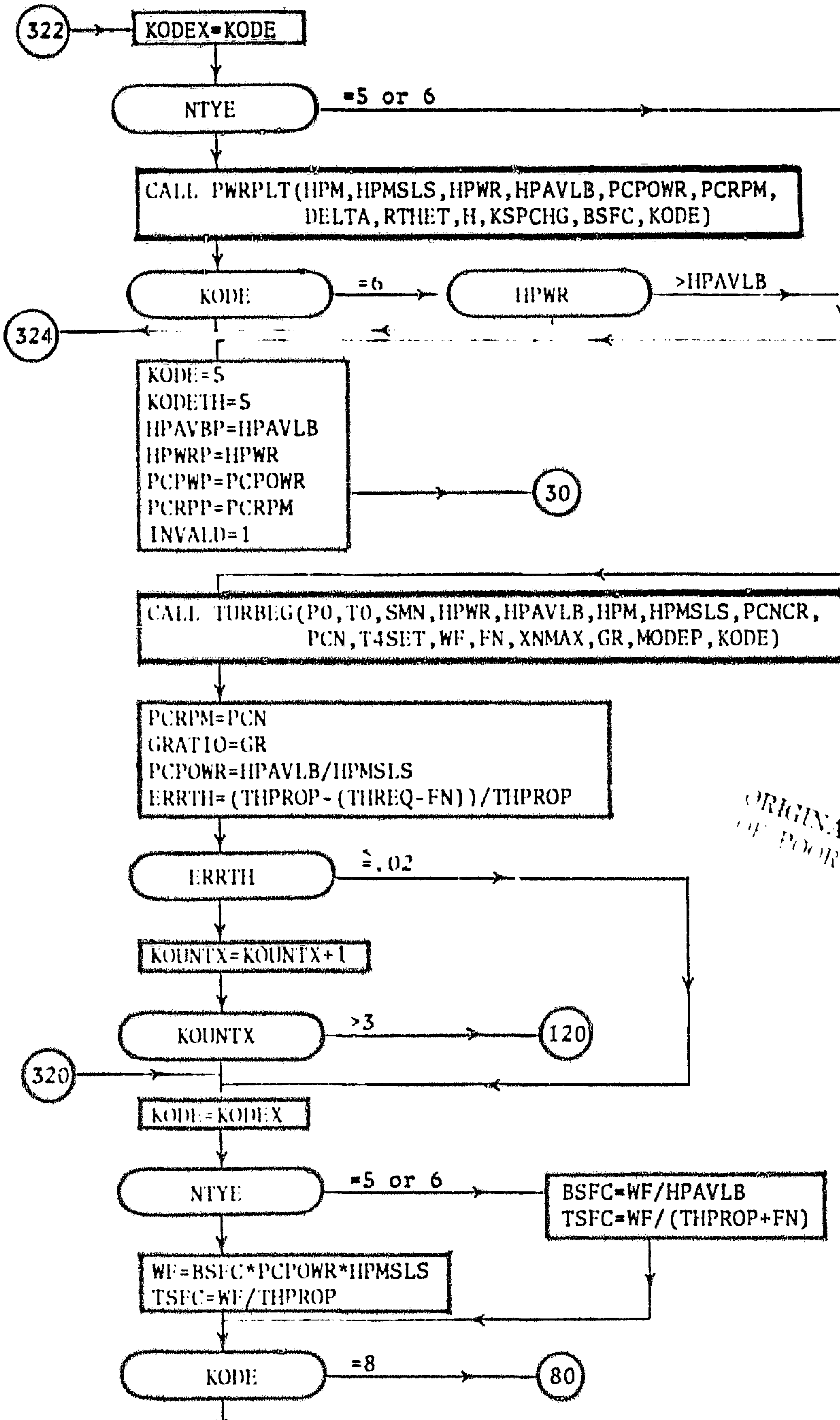

JEXIT
=1
TIPSPD
≤TSPDMX
DPROP=TSPMDX*60./(3.1416*XNMAX*GR)
JEXIT=1
11
TIPSPD
≤450
TIPSPD=450.
DPROP=TIPSPD*60./(3.1416*XNMAX*GR)
NTYP
≠6,16
CALL BIV(AF,BL,TIPSPD,ABL,ATIPS,AAF,6,4,NER)
AFT=BL*AF
AFT
<750
AF=750./BL
CALL BIV(COD,AF,TIPSPD,AAFX,ATIPS,ACOD,5,4,NER)
JEXIT=1
TIPSPD
=450
11
JC=0
JX=0
EFFP=1.
NTYE
=5 or 6
CALL PWRPLT(HPM,HPMSLS,HPWR,HAPVLB,PCPOWR,PCRPM,DELTA,
RTHET,H,KSPCHG,BSFC,KODE)
50
CALL TURBEG(P0,T0,SMN,HPWR,HPAVLB,HPM,HPMSLS,PCNCR,
PCN,T4SET,WF,FN,XNMAX,GR,MODEP,KODE)

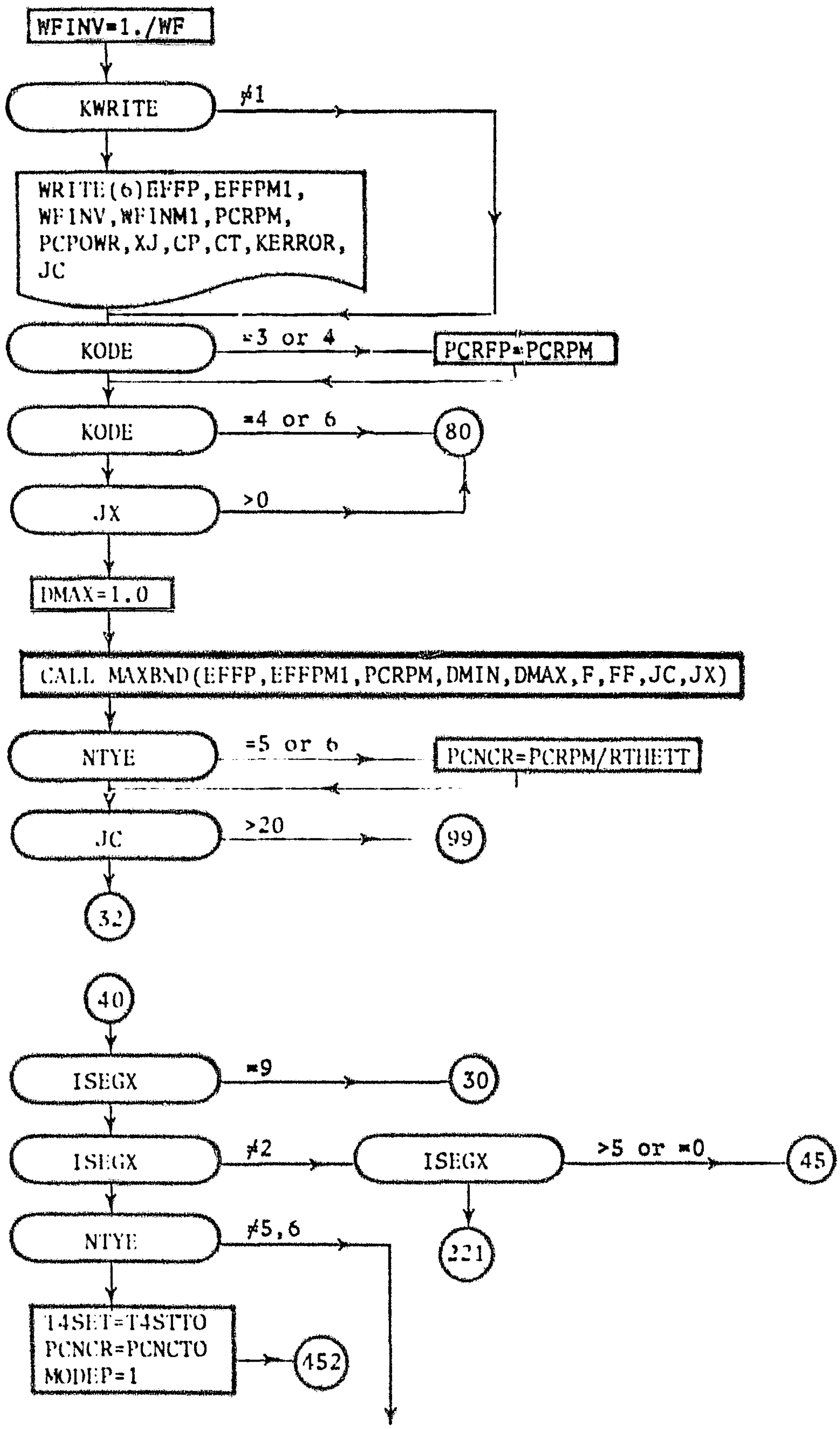

GRATIO=GR
PCRPM=PCN
PCPOWR=HPAVLB/HPMSLS
ERRTH=(THPROP-(THREQ-FN))/THPROP
ERRTH
≤.02
50
KOUNTX=KOUNTX+1
KOUNTX
>3
120
TROPI=(THREQ-FN)/(1.-FT)
11
20
NTYE
=5 or 6
CALL PWRPLT(HPM,HPMSLS,HPWR,HPAVLB,PCPOWR, PCRPM,DELTA,RTHET,H,KSPCHG,BSFC,KODE)
CALL TURBEG(P0,T0,SMN,HPWR,HPAVLB,HPM,HPMSLS,PCNCR, PCN,T4SET,WF,FN,XNMAX,GR,MODEP,KODE)
HPWR=HPAVLB
PCRPM=PCN
PCPOWR=HPAVLB/HPMSLS
TPROPI=(THRUST-FN)/(1.-FT)
DQ10=(TPROPI*RRHO/CTI/((XNMAX*PCRPM*GR/1000.)**2.)/6610.)**.25
DPROP=DQ10*10.
22
ERRM1=ERRD
CALL ENGDAT(PCRPM,GR,DPORP,TPROPI,SHP,EFFPI,VKTS, RRHO,KODE,IERROR,ENP,P0,T0,AF,BL)
THPROP=TPROPI*(1.-FT)
EFFP=EFFPI*(1.-FT)
CT=CT*(1.-FT)

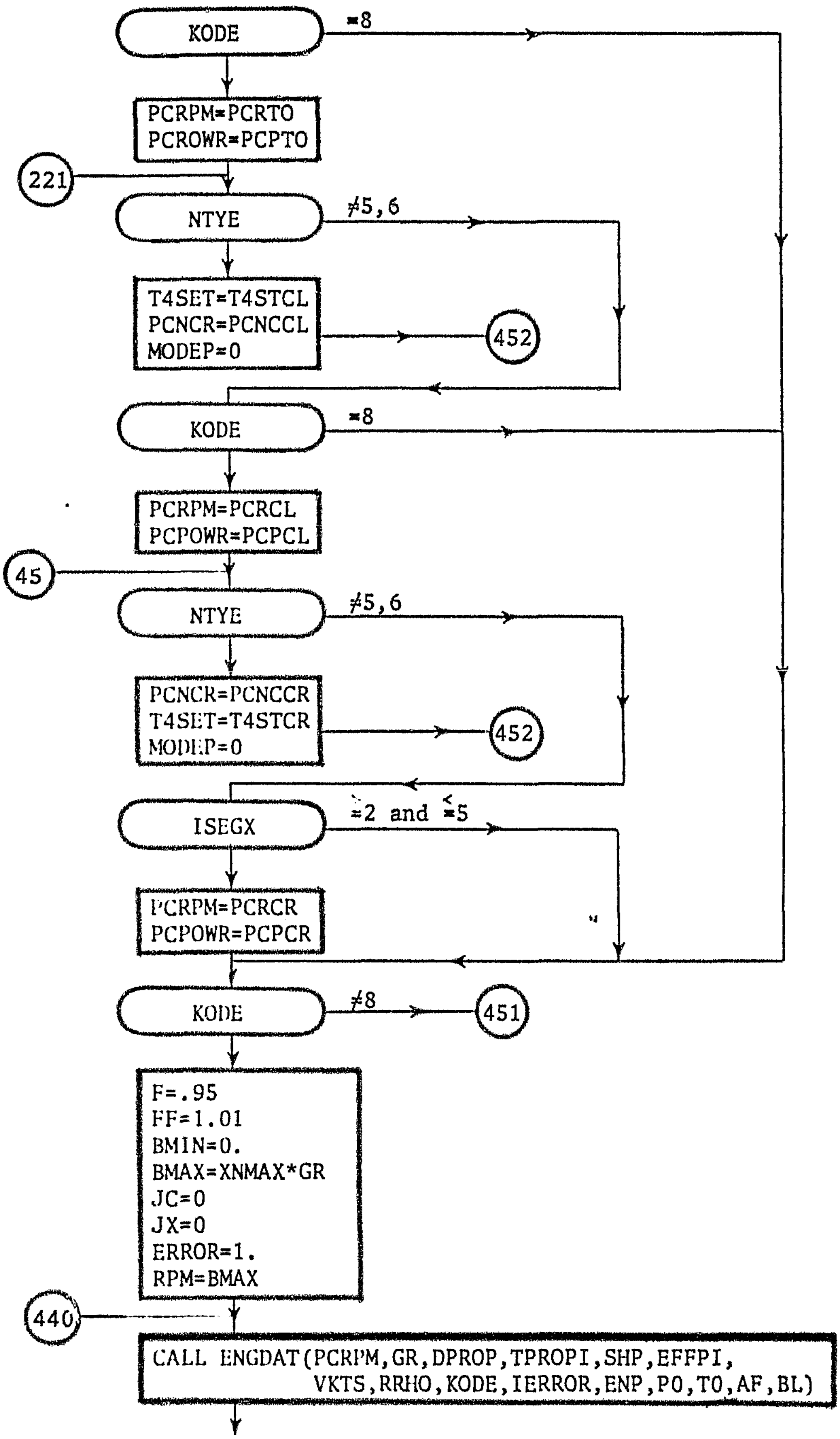

JX
>0
50
ERRD=(SHP-HPWR)/HPWR
KWRITE
≠1
WRITE(6)ERRD,ERRD1,
DROP,XJ,CP,CT,JC
ABS(ERRD)
<.005
50
CALL ITRMHW(ERRD,ERRM1,DPROP,F,FF,JC,JX)
JC
>20
WRITE(6)ERRD,
ERRM1,DPROP,KODE
RETURN
22
30
KOUNTX=0
KODE
≠8
351
PCRFP
=0
PCRFP=.95
PCRPM=PCRFP
CALL ENGDAT(PCRCM,GR,DPORP,TPORPI,SHP,EFFPI,VKTS,
RRHO,KODE,IERROR,ENP,P0,T0,AF,BL)
THPROP=TPROPI*(1.-FT)
EFFP=EFFPI*(1.-FT)
CT=CT*(1.-FT)
HPWR=SHP
KODE=9
CALL PWRPLT(HPM,HPMSLS,HPWR,HPAVLB,PCPOWR,PCRPM,DELTA,
RTHET,H,KSPCHG,BSFC,KODE)

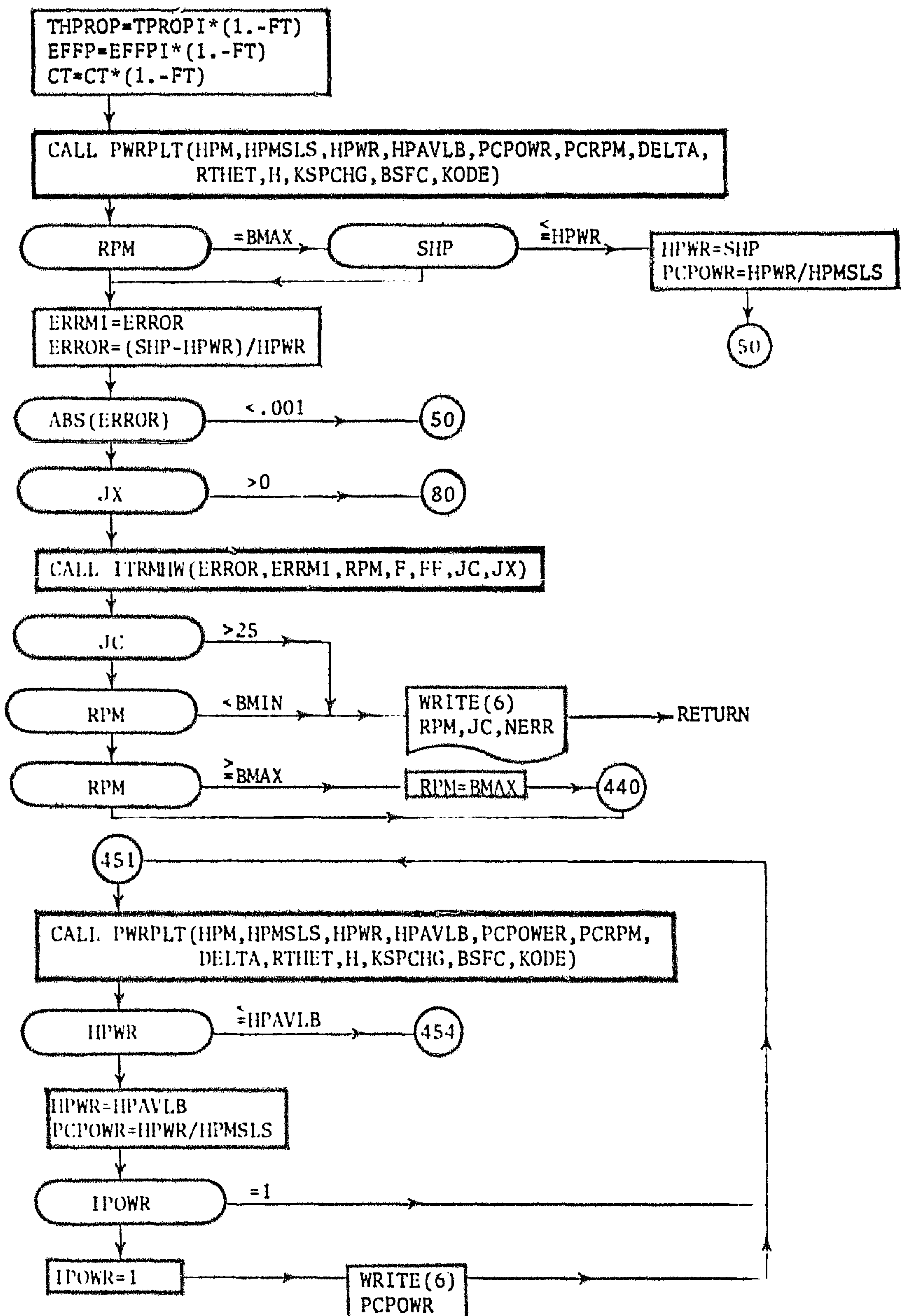

KODE=8
WF=BSFC*PCPOWR*HPMSLS
TSFC=WF/THPROP
80
351
KODE
=4 or 6
305
PCRPM=1.
F=.9
ERROR=999.
JC=0
JX=0
KWRITY=0
KODE
=5
KWRITY=1
THREQ=THRUST
THPROP=THREQ-FN
TPROPI=THPROP/(1.-FT)
307
ERRM1=ERROR
CALL ENGDAT(PCRPM,GR,DPROP,TPROPI,SHP,EFFDI,VKTS,
RRHO,KODE,IERROR,ENP,P0,T0,AF,BL)
THPROP=TPROPI*(1.-FT)
EFFP=EFFPI*(.1-FT)
CT=CT*(1.-FT)
HPRW=SHP
CALL PWRPLT(HPM,HPMSLS,HPWR,HPAVLB,PCPOWR,PCRPM,
DELTA,RTHET,H,KSPCHG,BSFC,KODE)
ERROR=(SHP-HPAVLB)/HPAVLB
KWRITE
=1
WRITE(6)PCPOWR,
PCRPM,SHP,HPAVLB
ERROR
ABS(ERROR)
<.001
308

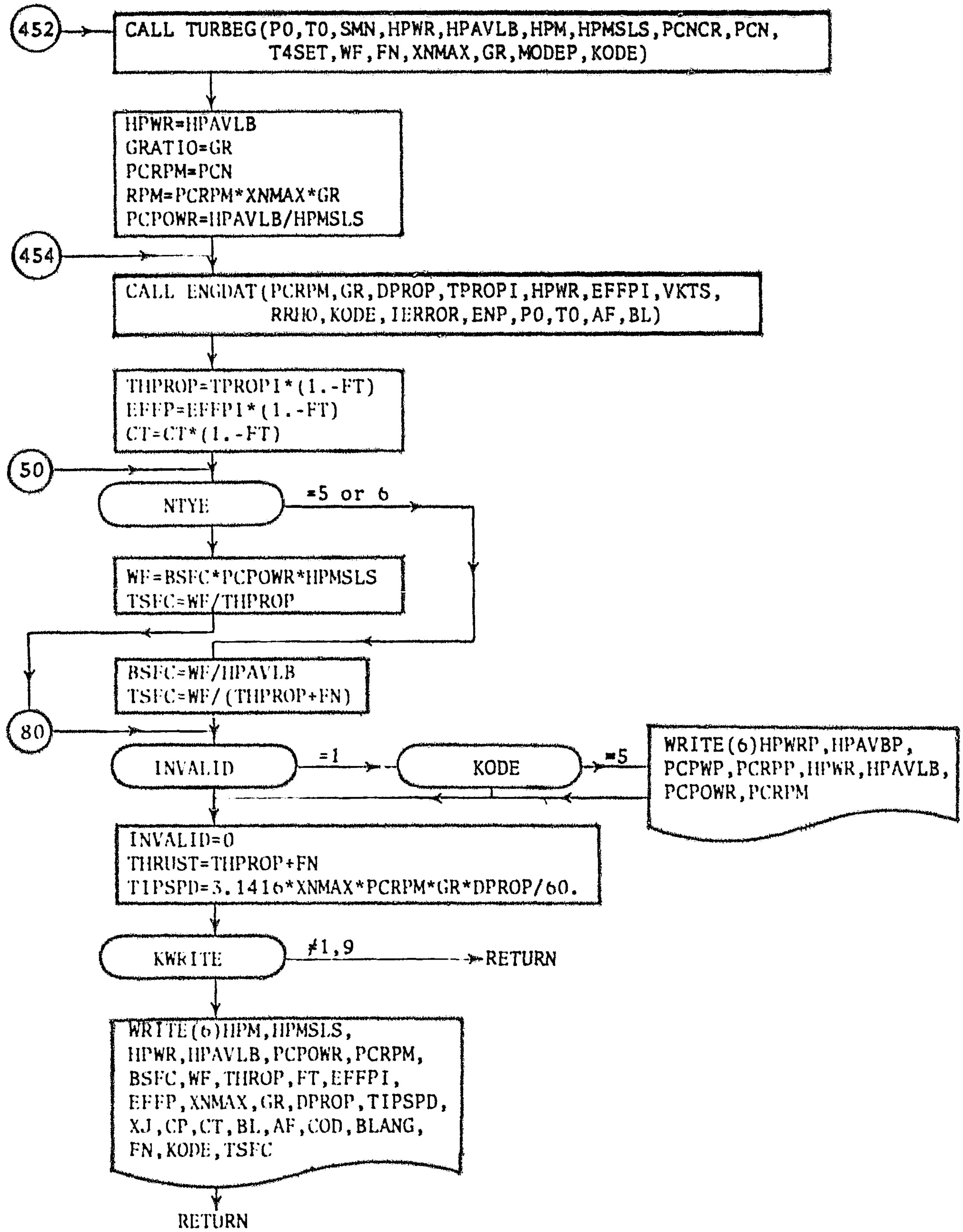

CALL ITRMHW(ERROR,ERRM1,PCRPM,F,FF,JC,JX)
JC
≥2
PCRPM
>1
WRITE(6)ERRD, ERRM1,DPROP,KODE
PCRPM
≤.50
PCRPM=.5
JC
>25
WRITE(6)ERRP,ERRM1, PCRPM,KODE
RETURN
308
DMIN=PCRPM
PCRPM=1.
305
NTYE
≠5 and 6
PCNCR=PCNCCR
306
PCRPM=PCNCR*RTHETT
T4SET=T4STCR
KWRITY=0
KODE
=5
KWRITY=1
F=.9
FF=1.02
WFINV=1.
JC=0
JX=0
THREQ=THRUST
EFFPM1=EFFP
WFINM1=WFINV
320
THPROP=THREQ-FN
TPROPI=THPROP/(1.-FT)
CALL ENGDAT(PCRPM,GR,DPROP,TPROPI,HPWR,EFFPI, VKTS,RRHO,KODE,IERROR,ENP,PO,TO,AF,BL)
THPROP=TPROPI*(1.-FT)
EFFP=EFFPI*(1.-FT)
CT=CT*(1.-FT)

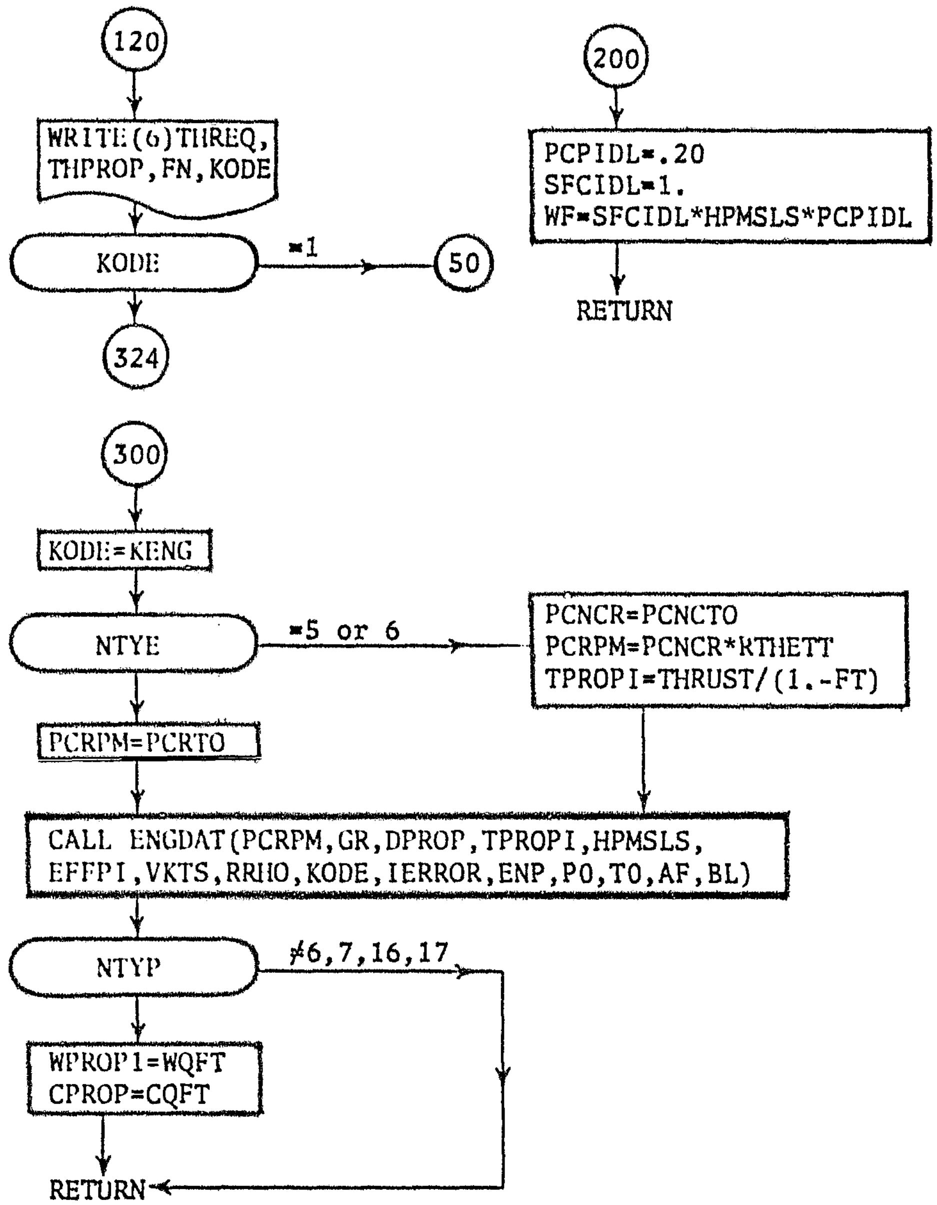

322
KODEX=KODE
NTYE
=5 or 6
CALL PWRPLT(HPM,HPMSLS,HPWR,HPAVLB,PCPOWR,PCRPM, DELTA,RTHET,H,KSPCHG,BSFC,KODE)
KODE
=6
HPWR
>HPAVLB
324
KODE=5
KODETH=5
HPAVBP=HPAVLB
HPWRP=HPWR
PCPWP=PCPOWR
PCRPP=PCRPM
INVALD=1
30
CALL TURBEG(P0,T0,SMN,HPWR,HPAVLB,HPM,HPMSLS,PCNCR, PCN,T4SET,WF,FN,XNMAX,GR,MODEP,KODE)
PCRPM=PCN
GRATIO=GR
PCPOWR=HPAVLB/HPMSLS
ERRTH=(THPROP-(THREQ-FN))/THPROP
ERRTH
≥.02
KOUNTX=KOUNTX+1
KOUNTX
>3
120
320
KODE=KODEX
NTYE
=5 or 6
BSFC=WF/HPAVLB
TSFC=WF/(THPROP+FN)
WF=BSFC*PCPOWR*HPMSLS
TSFC=WF/THPROP
KODE
=8
80


WFINV=1./WF
KWRITE
≠1
WRITE(6)EFFP,EFFPM1,
WFINV,WFINM1,PCRPM,
PCPOWR,XJ,CP,CT,KERROR,
JC
KODE
=3 or 4
PCRFP=PCRPM
KODE
=4 or 6
80
JX
>0
DMAX=1.0
CALL MAXBND(EFFP,EFFPM1,PCRPM,DMIN,DMAX,F,FF,JC,JX)
NTYE
=5 or 6
PCNCR=PCRPM/RTHETT
JC
>20
99
32
40
ISEGX
=9
30
ISEGX
≠2
ISEGX
>5 or =0
45
221
NTYE
≠5,6
T4SET=T4STTO
PCNCR=PCNCTO
MODEP=1
452


KODE
=8
PCRPM=PCRTO
PCROWR=PCPTO
221
NTYE
≠5,6
T4SET=T4STCL
PCNCR=PCNCCL
MODEP=0
452
KODE
=8
PCRPM=PCRCL
PCPOWR=PCPCL
45
NTYE
≠5,6
PCNCR=PCNCCR
T4SET=T4STCR
MODEP=0
452
ISEGX
≥2 and ≤5
PCRPM=PCRCR
PCPOWR=PCPCR
KODE
≠8
451
F=.95
FF=1.01
BMIN=0.
BMAX=XNMAX*GR
JC=0
JX=0
ERROR=1.
RPM=BMAX
440
CALL ENGDAT(PCRPM,GR,DPROP,TPROPI,SHP,EFFPI,
VKTS,RRHO,KODE,IERROR,ENP,P0,T0,AF,BL)


THPROP=TPROPI*(1.-FT)
EFFP=EFFPI*(1.-FT)
CT=CT*(1.-FT)
CALL PWRPLT(HPM,HPMSLS,HPWR,HPAVLB,PCPOWR,PCRPM,DELTA, RTHET,H,KSPCHG,BSFC,KODE)
RPM
=BMAX
SHP
≦HPWR
HPWR=SHP
PCPOWR=HPWR/HPMSLS
50
ERRM1=ERROR
ERROR=(SHP-HPWR)/HPWR
ABS(ERROR)
<.001
50
JX
>0
80
CALL ITRMHW(ERROR,ERRM1,RPM,F,FF,JC,JX)
JC
>25
RPM
<BMIN
WRITE(6)
RPM,JC,NERR
RETURN
RPM
≧BMAX
RPM=BMAX
440
451
CALL PWRPLT(HPM,HPMSLS,HPWR,HPAVLB,PCPOWER,PCRPM, DELTA,RTHET,H,KSPCHG,BSFC,KODE)
HPWR
≦HPAVLB
454
HPWR=HPAVLB
PCPOWR=HPWR/HPMSLS
IPOWR
=1
IPOWR=1
WRITE(6)
PCPOWR


452
CALL TURBEG(P0,T0,SMN,HPWR,HPAVLB,HPM,HPMSLS,PCNCR,PCN,
T4SET,WF,FN,XNMAX,GR,MODEP,KODE)
HPWR=HPAVLB
GRATIO=GR
PCRPM=PCN
RPM=PCRPM*XNMAX*GR
PCPOWR=HPAVLB/HPMSLS
454
CALL ENGDAT(PCRPM,GR,DPROP,TPROPI,HPWR,EFFPI,VKTS,
RRHO,KODE,IERROR,ENP,P0,T0,AF,BL)
THPROP=TPROPI*(1.-FT)
EFFP=EFFPI*(1.-FT)
CT=CT*(1.-FT)
50
NTYE
=5 or 6
WF=BSFC*PCPOWR*HPMSLS
TSFC=WF/THPROP
BSFC=WF/HPAVLB
TSFC=WF/(THPROP+FN)
80
INVALID
=1
KODE
=5
WRITE(6)HPWRP,HPAVBP,
PCPWP,PCRPP,HPWR,HPAVLB,
PCPOWR,PCRPM
INVALID=0
THRUST=THPROP+FN
TIPSPD=3.1416*XNMAX*PCRPM*GR*DPROP/60.
KWRITE
≠1,9
RETURN
WRITE(6)HPM,HPMSLS,
HPWR,HPAVLB,PCPOWR,PCRPM,
BSFC,WF,THROP,FT,EFFPI,
EFFP,XNMAX,GR,DPROP,TIPSPD,
XJ,CP,CT,BL,AF,COD,BLANG,
FN,KODE,TSFC
RETURN


120
WRITE(6)THREQ,
THPROP,FN,KODE
KODE
=1
50
324
200
PCPIDL=.20
SFCIDL=1.
WF=SFCIDL*HPMSLS*PCPIDL
RETURN
300
KODE=KENG
NTYE
=5 or 6
PCNCR=PCNCTO
PCRPM=PCNCR*RTHETT
TPROPI=THRUST/(1.-FT)
PCRPM=PCRTO
CALL ENGDAT(PCRPM,GR,DPROP,TPROPI,HPMSLS,
EFFPI,VKTS,RRHO,KODE,IERROR,ENP,P0,T0,AF,BL)
NTYP
≠6,7,16,17
WPROP1=WQFT
CPROP=CQFT
RETURN

IV.3.2.2 Subroutine ENGDAT, Propeller Characteristics. This routine controls propeller performance, cost, weight, and noise computations. Subroutine PERFM (Section IV.1.3) provides performance calculations; subroutine ZNOISE (Section IV.1.3.5), provides noise calculations; subroutine COST (Section IV.1.3.2), provides costs; subroutine WAIT, (Section IV.1.3.4), provides weight calculations. Gearbox characteristics are computed through subroutine GEARBX (Section IV.1.3.3). The utility routines BIV (Section I.1.3.4) and ITRLN, (Section I.1.3.7), are also employed by subroutine ENGDAT.

A detailed flow chart for ENGDAT is provided in Figure IV.3.5.

ENGDAT - PROPELLER VERSION

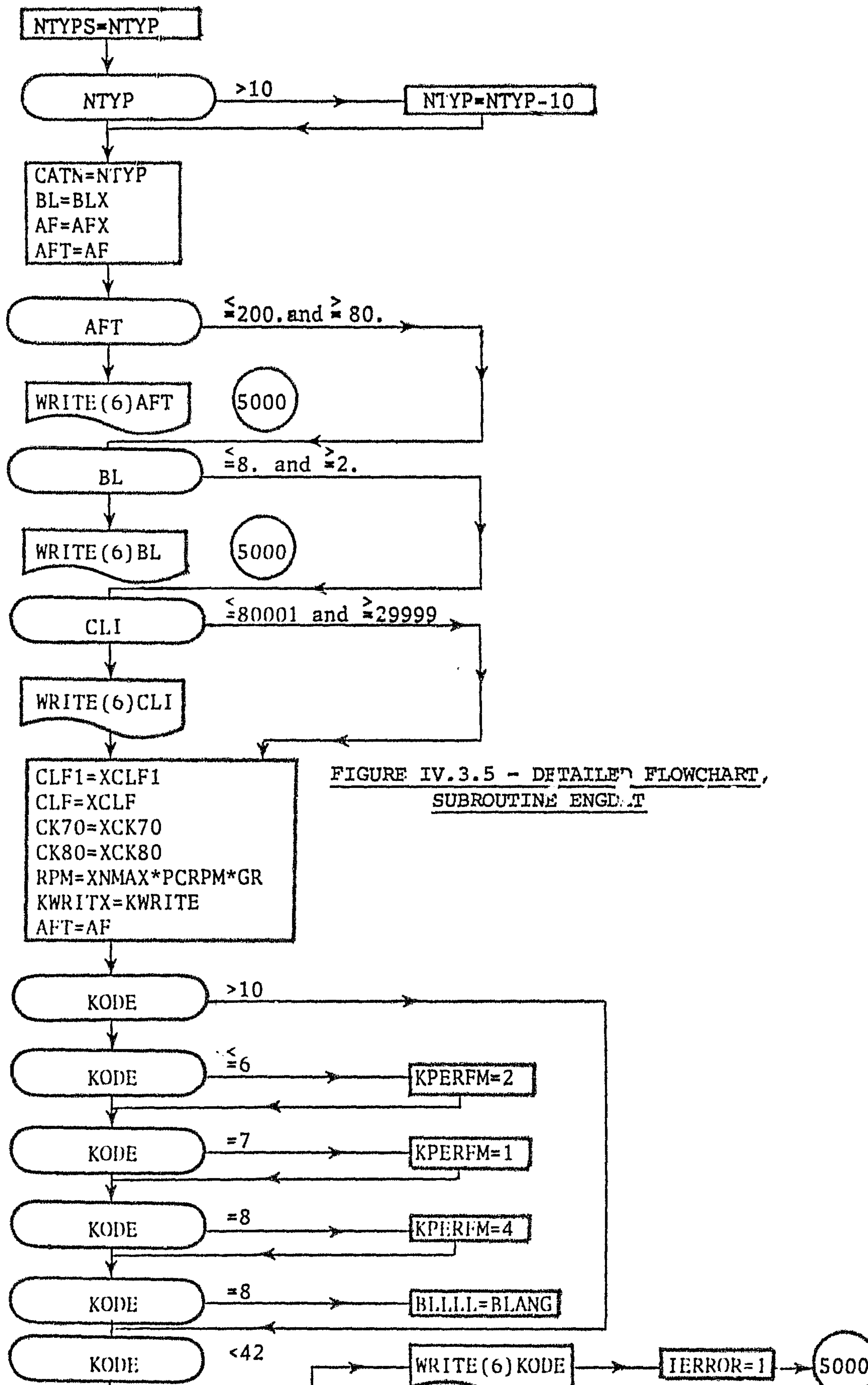
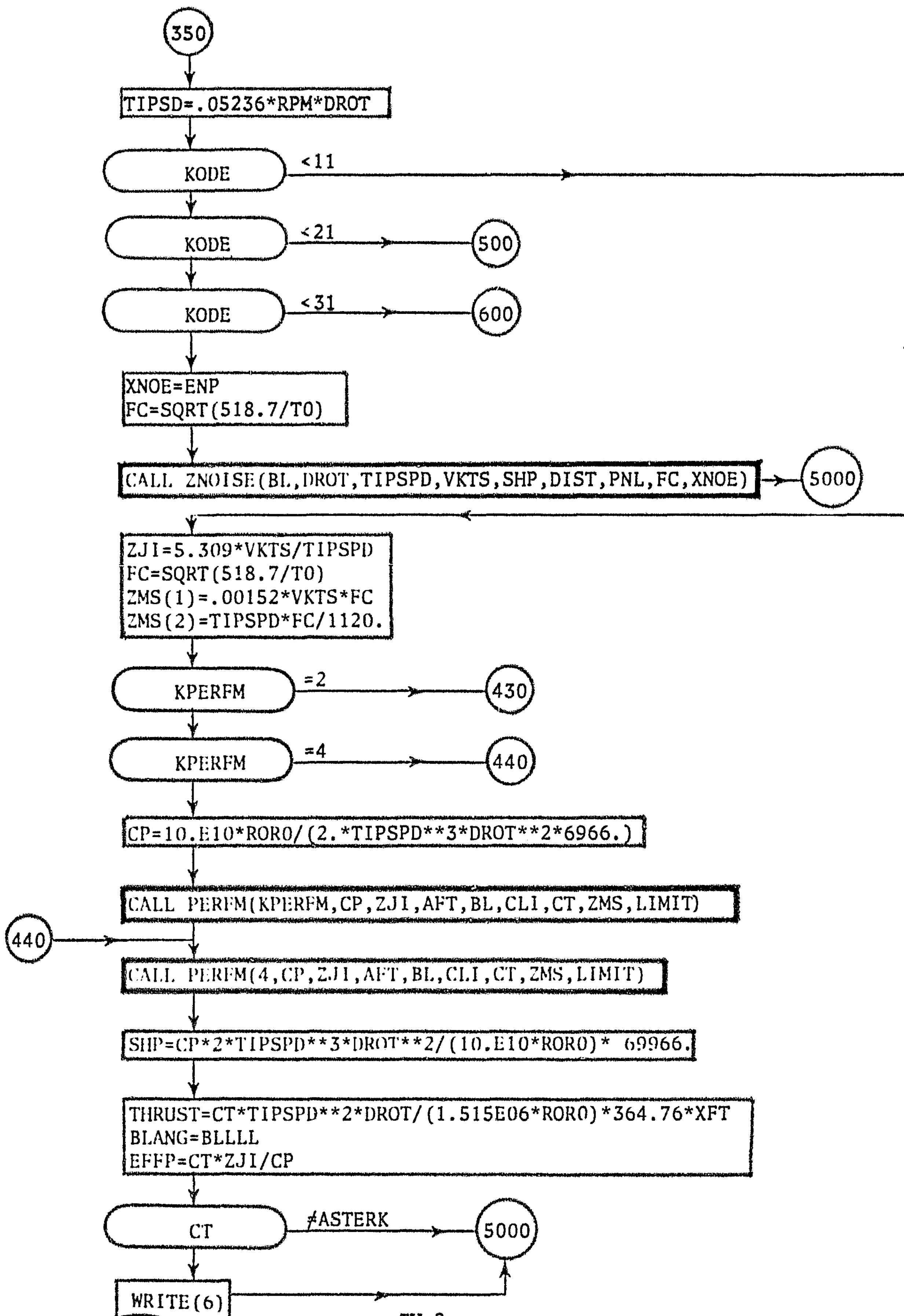
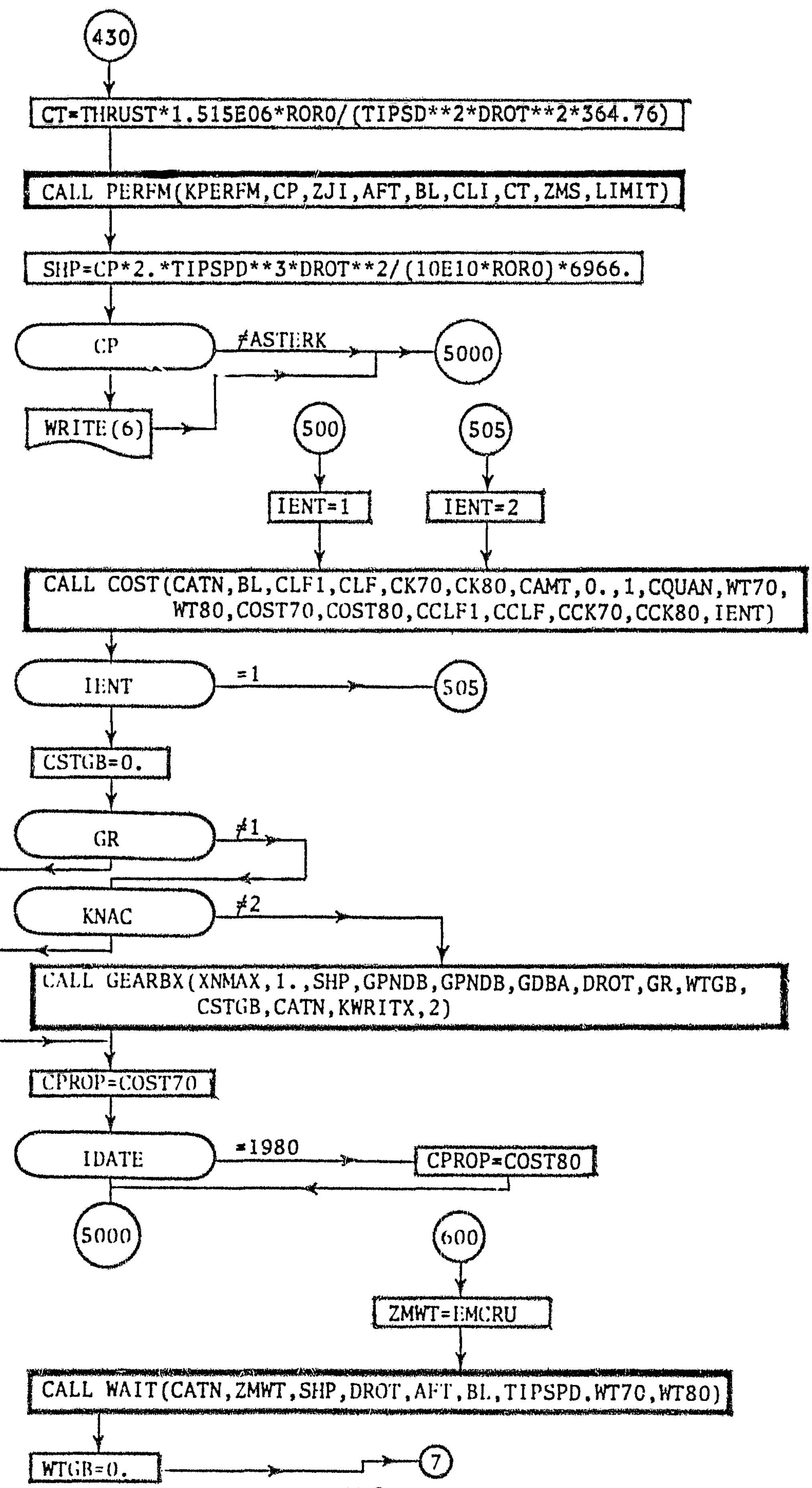
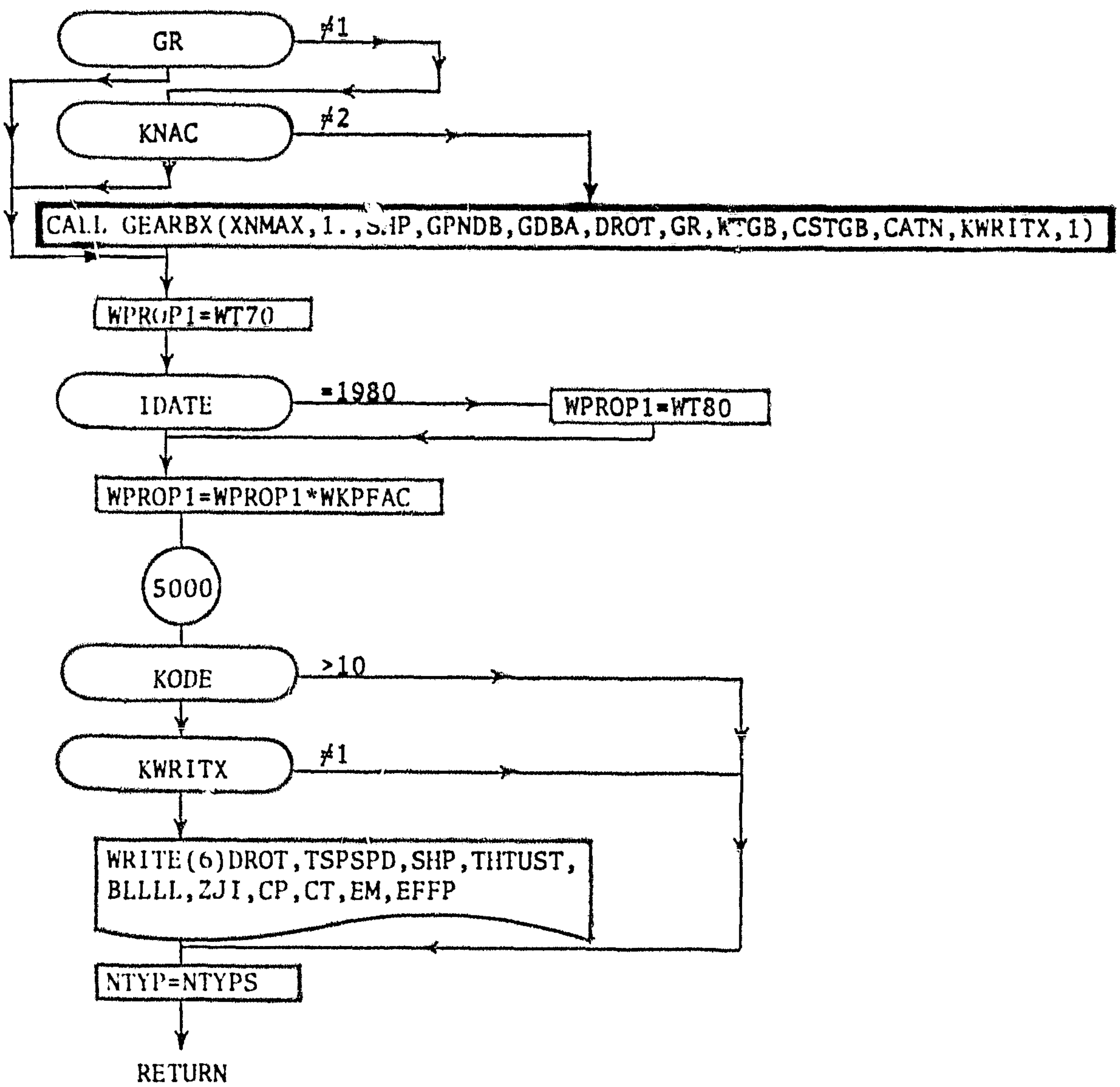


FIGURE IV.3.5 - DETAILED FLOWCHART, SUBROUTINE ENGDAT


350
TIPSD=.05236*RPM*DROT
KODE
<11
KODE
<21
500
KODE
<31
600
XNOE=ENP
FC=SQRT(518.7/T0)
CALL ZNOISE(BL,DROT,TIPSPD,VKTS,SHP,DIST,PNL,FC,XNOE)
5000
ZJI=5.309*VKTS/TIPSPD
FC=SQRT(518.7/T0)
ZMS(1)=.00152*VKTS*FC
ZMS(2)=TIPSPD*FC/1120.
KPERFM
=2
430
KPERFM
=4
440
CP=10.E10*RORO/(2.*TIPSPD**3*DROT**2*6966.)
CALL PERFM(KPERFM,CP,ZJI,AFT,BL,CLI,CT,ZMS,LIMIT)
440
CALL PERFM(4,CP,ZJI,AFT,BL,CLI,CT,ZMS,LIMIT)
SHP=CP*2*TIPSPD**3*DROT**2/(10.E10*RORO)* 69966.
THRUST=CT*TIPSPD**2*DROT/(1.515E06*RORO)*364.76*XFT
BLANG=BLLLL
EFFP=CT*ZJI/CP
CT
≠ASTERK
5000
WRITE(6)



430
CT=THRUST*1.515E06*RORO/(TIPSD**2*DROT**2*364.76)
CALL PERFM(KPERFM,CP,ZJI,AFT,BL,CLI,CT,ZMS,LIMIT)
SHP=CP*2.*TIPSPD**3*DROT**2/(10E10*RORO)*6966.
CP
≠ASTERK
5000
WRITE(6)
500
505
IENT=1
IENT=2
CALL COST(CATN,BL,CLF1,CLF,CK70,CK80,CAMT,0.,1,CQUAN,WT70, WT80,COST70,COST80,CCLF1,CCLF,CCK70,CCK80,IENT)
IENT
=1
505
CSTGB=0.
GR
≠1
KNAC
≠2
CALL GEARBX(XNMAX,1.,SHP,GPNDB,GPNDB,GDBA,DROT,GR,WTGB, CSTGB,CATN,KWRITX,2)
CPROP=COST70
IDATE
=1980
CPROP=COST80
5000
600
ZMWT=EMCRU
CALL WAIT(CATN,ZMWT,SHP,DROT,AFT,BL,TIPSPD,WT70,WT80)
WTGB=0.
7


GR
≠1
KNAC
≠2
CALL GEARBX(XNMAX,1.,SHP,GPNDB,GDBA,DROT,GR,WTGB,CSTGB,CATN,KWRITX,1)
WPROP1=WT70
IDATE
=1980
WPROP1=WT80
WPROP1=WPROP1*WKPFAC
5000
KODE
>10
KWRITX
≠1
WRITE(6)DROT,TSPSPD,SHP,THTUST,
BLLLL,ZJI,CP,CT,EM,EFFP
NTYP=NTYPS
RETURN

IV.3.2.3 Subroutine ENGSZ, Propeller Driven Engine Sizing. Subroutine ENGSZ controls the propeller driven engine sizing calculations. The engine is sized to meet cruise, take-off, and/or climb requirements using the methods of Section IV.1.2.1. Subroutines called by ENGSZ include ENGINE for engine/propeller matching (Section IV.1.2.2); PERFM for propeller performance (Section IV.1.3.1); APPFLP for flap setting (Section III.1.4.4); DRAG for configuration drag (Section III.1.2.2); TPALT for atmospheric characteristics (Section I.1.3.15); ENGWGT for engine weights (Volume V); and the utility routines ITRMHW (Section I.1.3.8).

A detailed flow chart for subroutine ENGSZ is presented in Figure IV.3.6.

ENGSZ

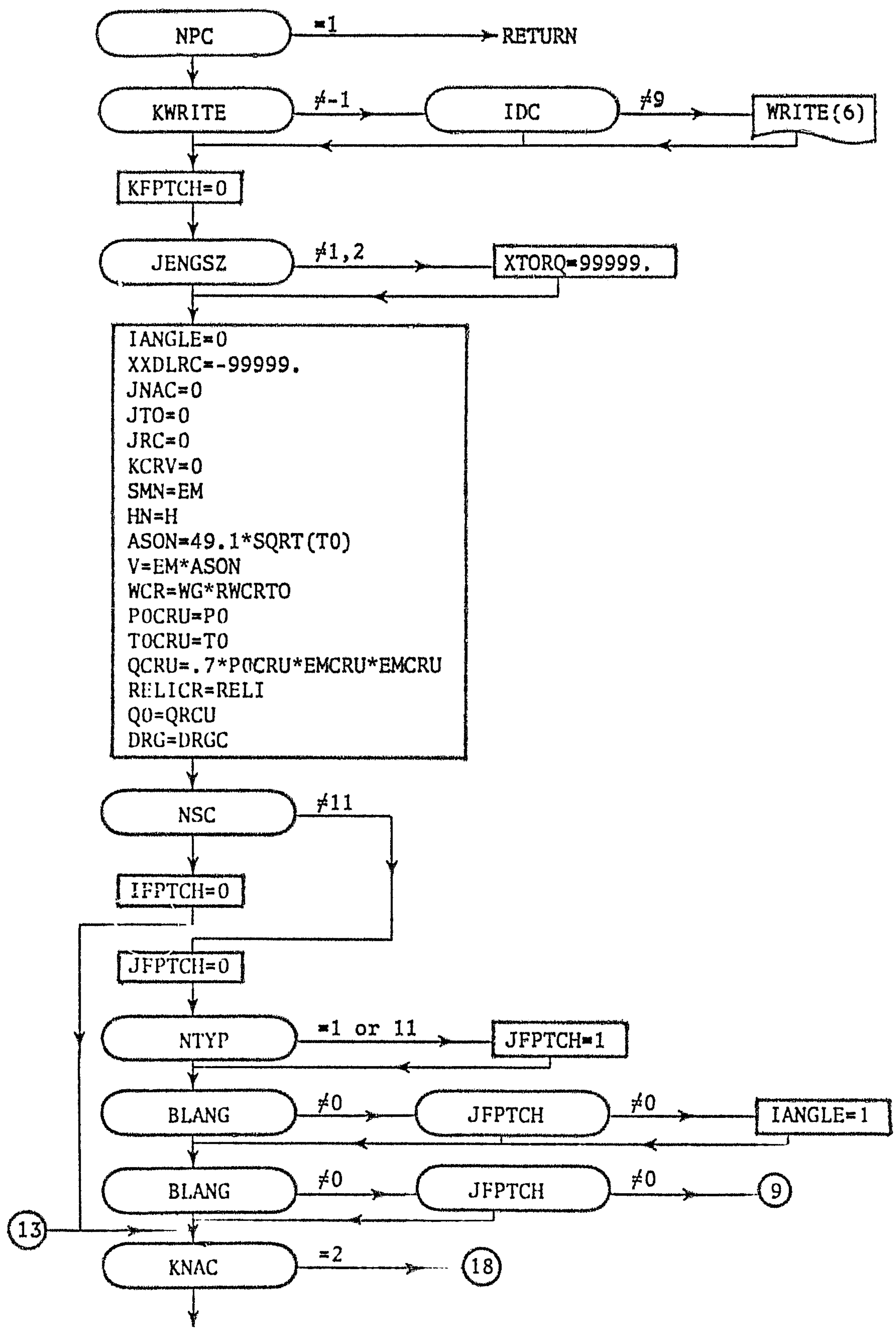
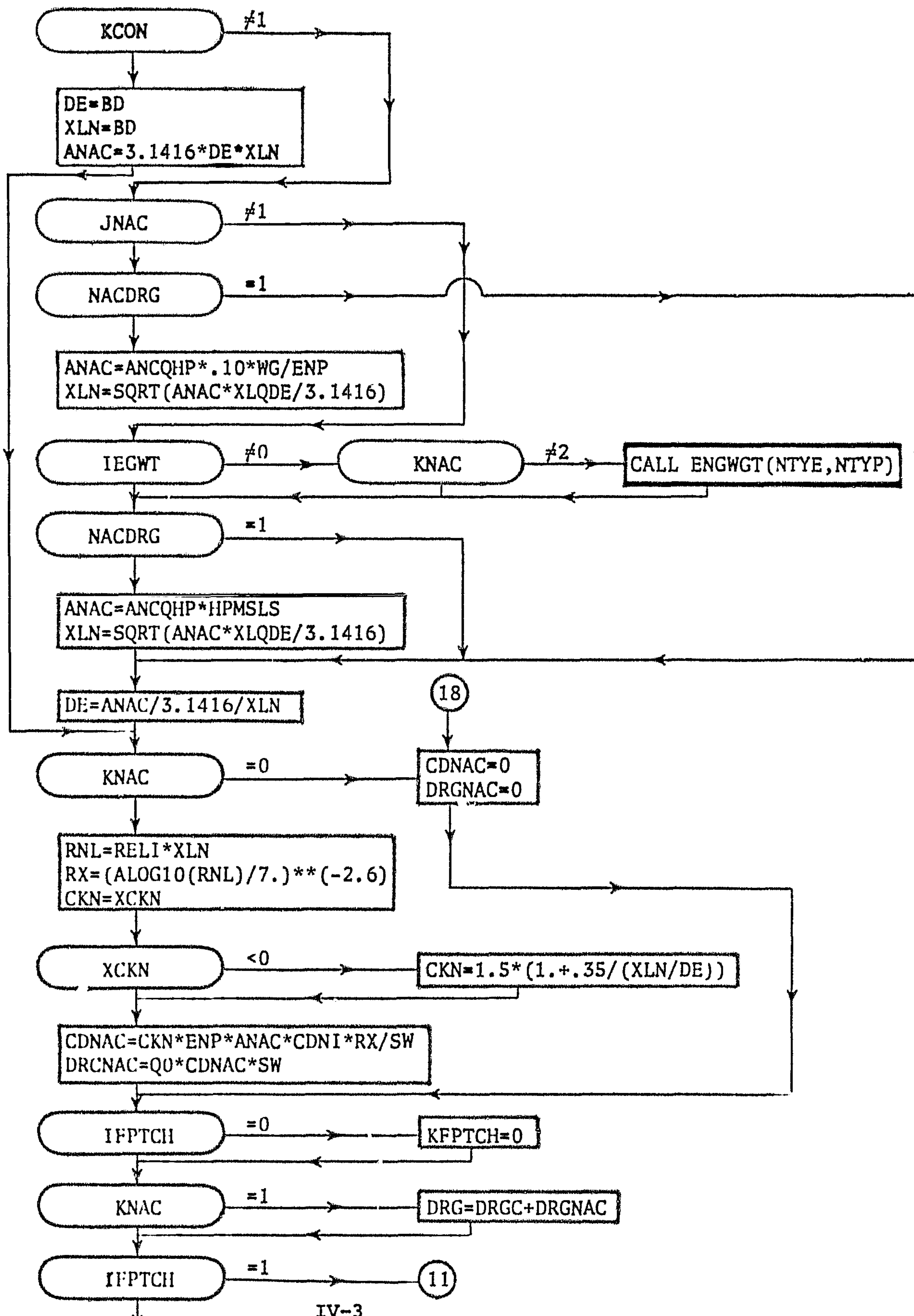
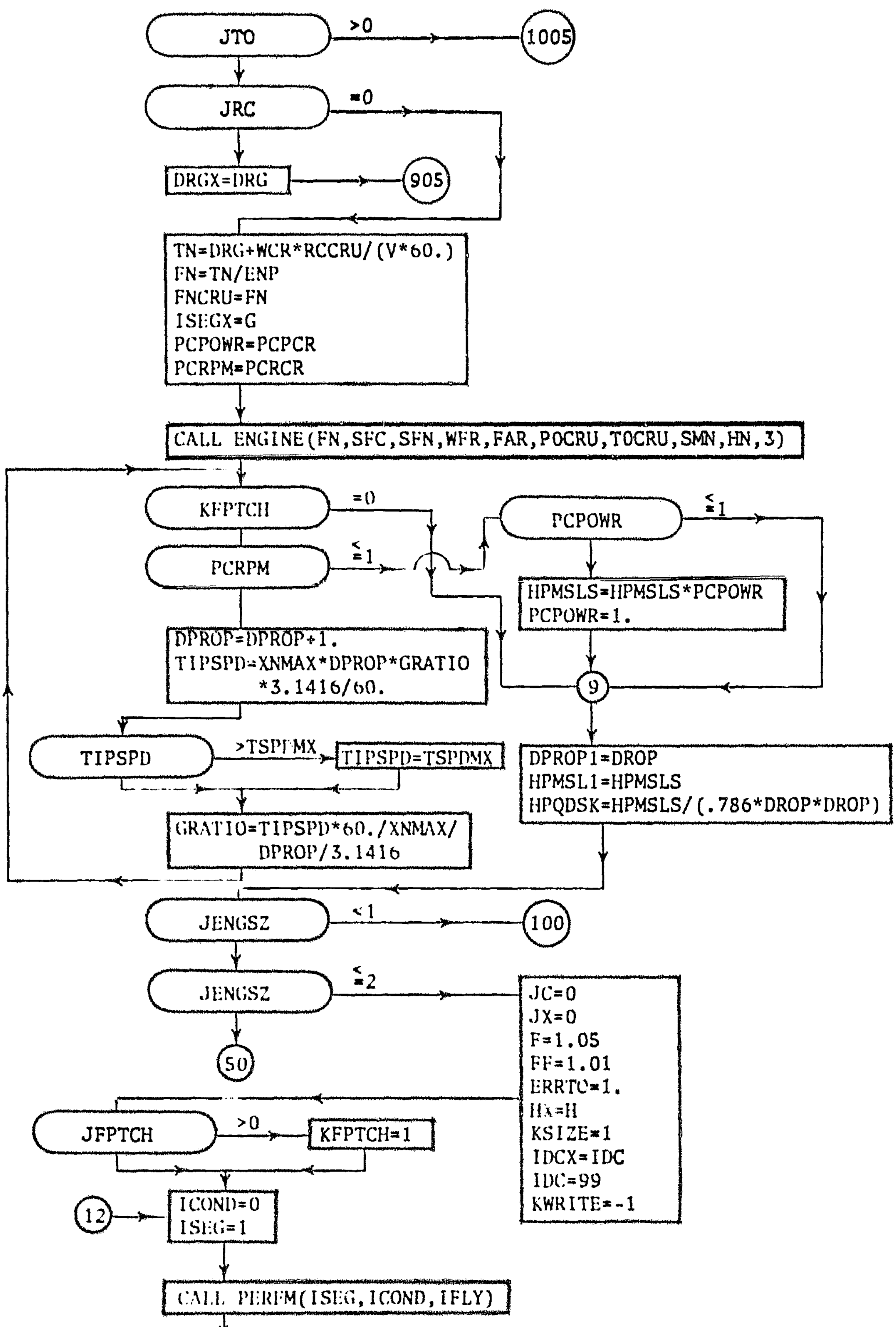
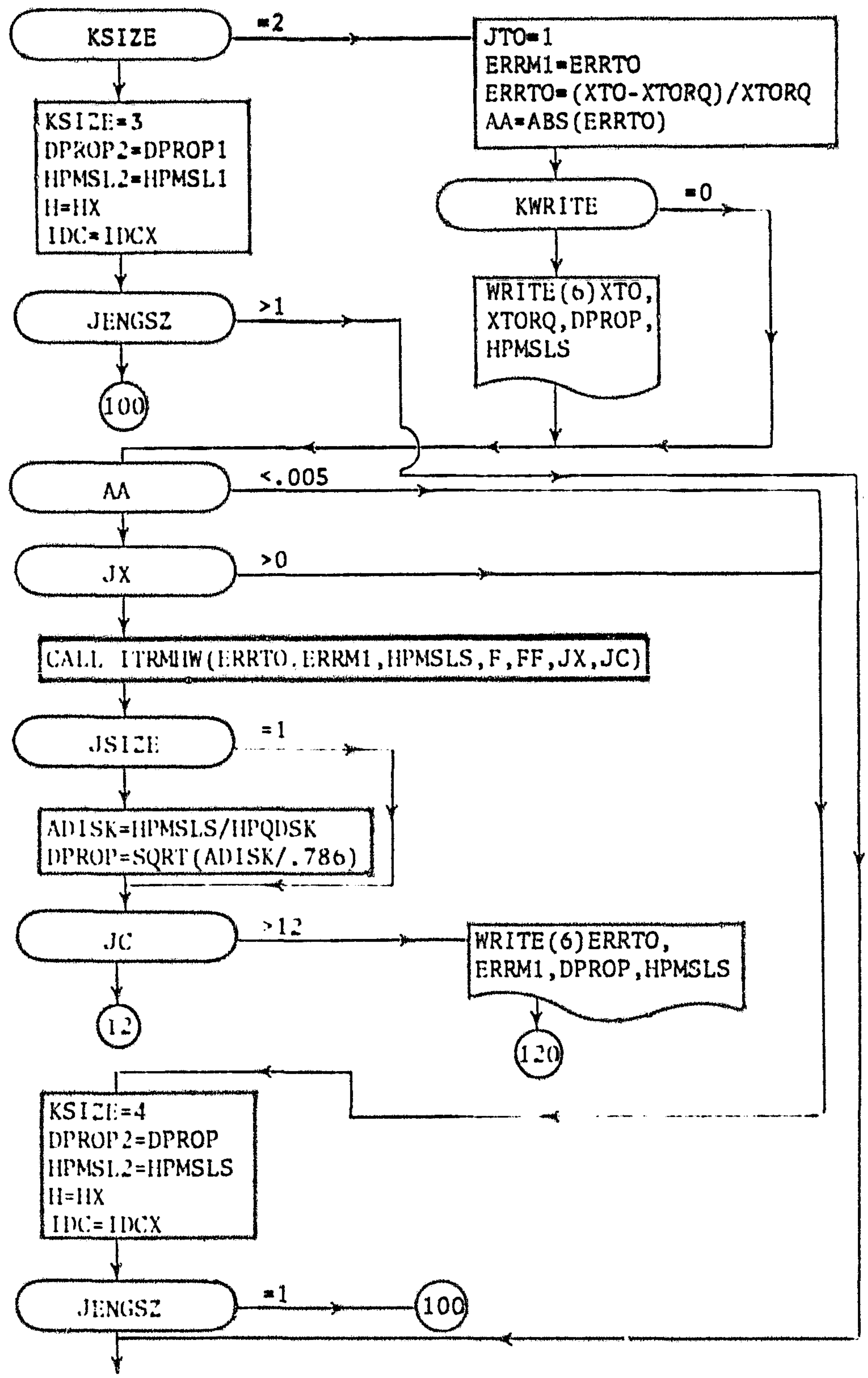
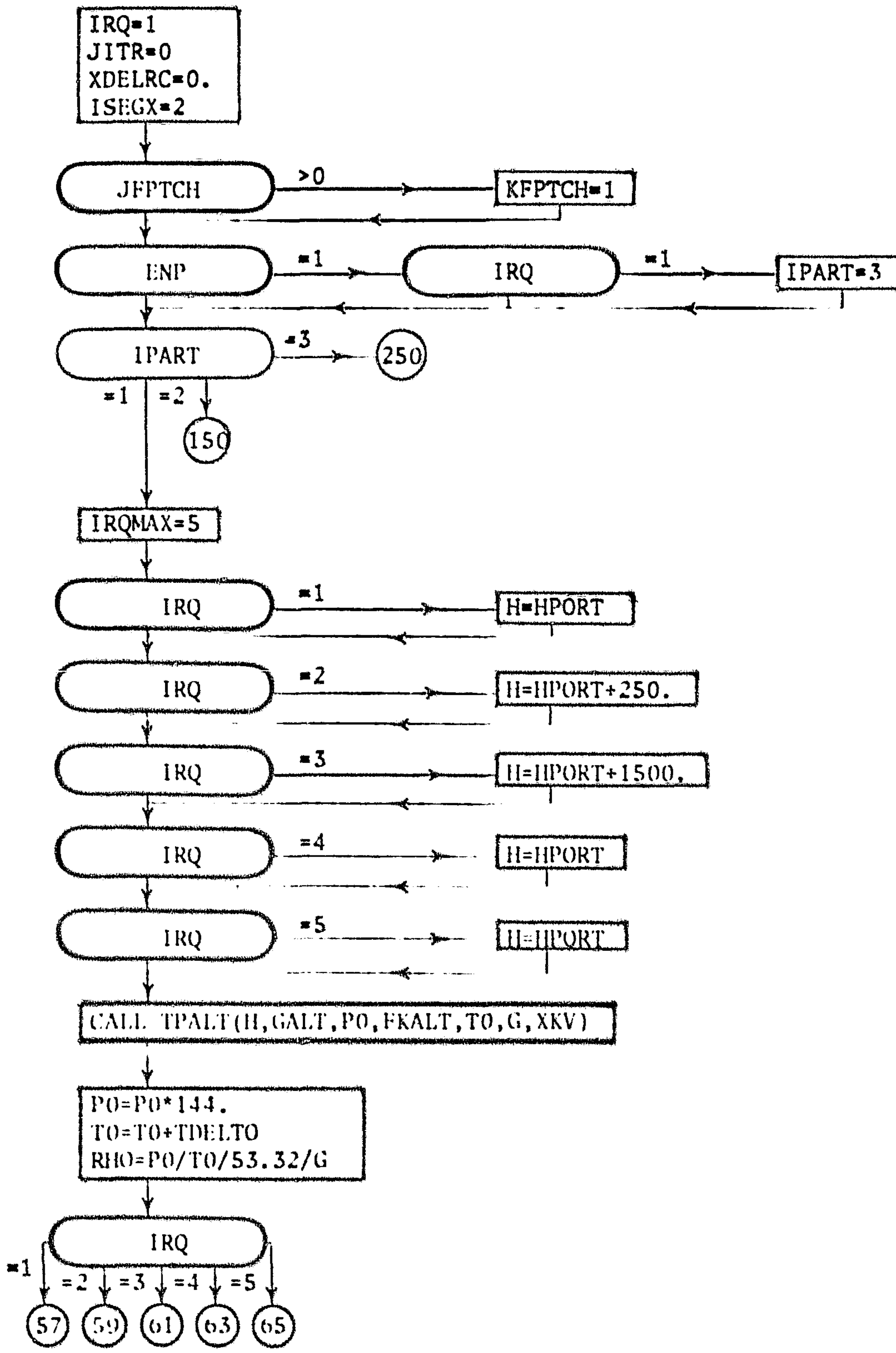


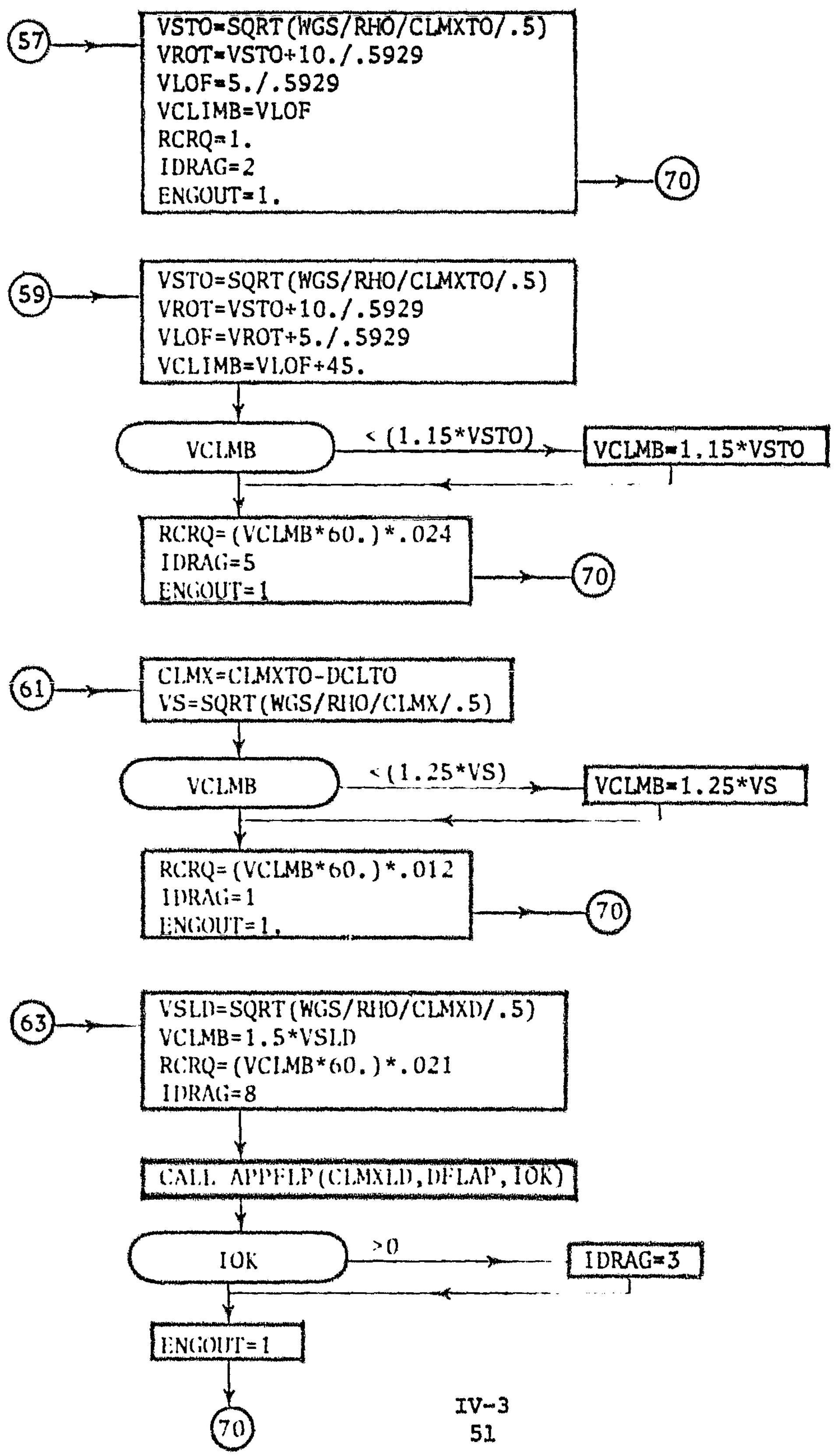
FIGURE IV.3.6 - DETAILED FLOWCHART, SUBROUTINE ENGSZ - PROPELLER DRIVEN ENGINE SIZING

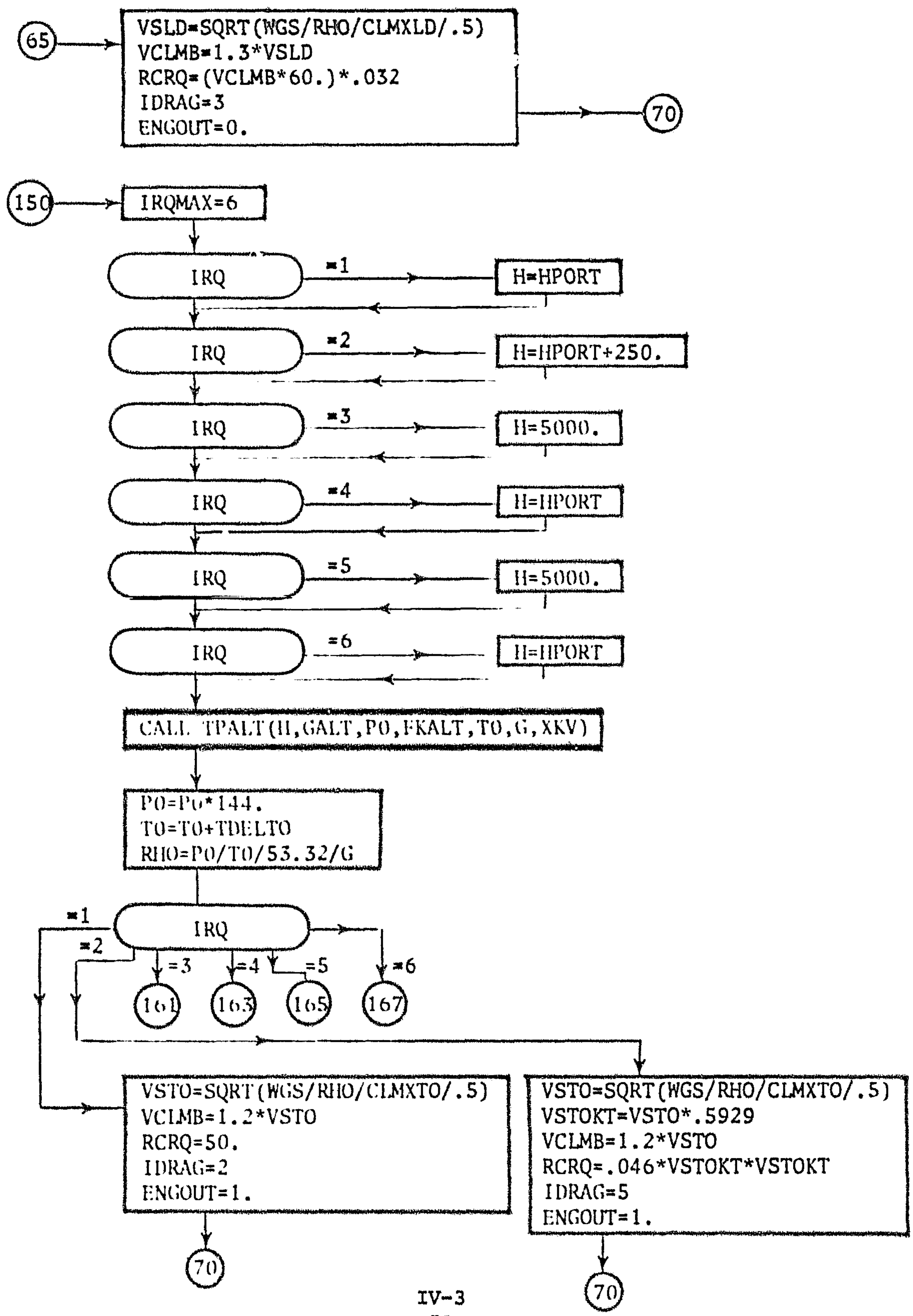

KCON
≠1
DE=BD
XLN=BD
ANAC=3.1416*DE*XLN
JNAC
≠1
NACDRG
=1
ANAC=ANCQHP*.10*WG/ENP
XLN=SQRT(ANAC*XLQDE/3.1416)
IEGWT
≠0
KNAC
≠2
CALL ENGWGT(NTYE,NTYP)
NACDRG
=1
ANAC=ANCQHP*HPMSLS
XLN=SQRT(ANAC*XLQDE/3.1416)
DE=ANAC/3.1416/XLN
18
KNAC
=0
CDNAC=0
DRGNAC=0
RNL=RELI*XLN
RX=(ALOG10(RNL)/7.)**(-2.6)
CKN=XCKN
XCKN
<0
CKN=1.5*(1.+.35/(XLN/DE))
CDNAC=CKN*ENP*ANAC*CDNI*RX/SW
DRGNAC=Q0*CDNAC*SW
IFPTCH
=0
KFPTCH=0
KNAC
=1
DRG=DRGC+DRGNAC
IFPTCH
=1
11

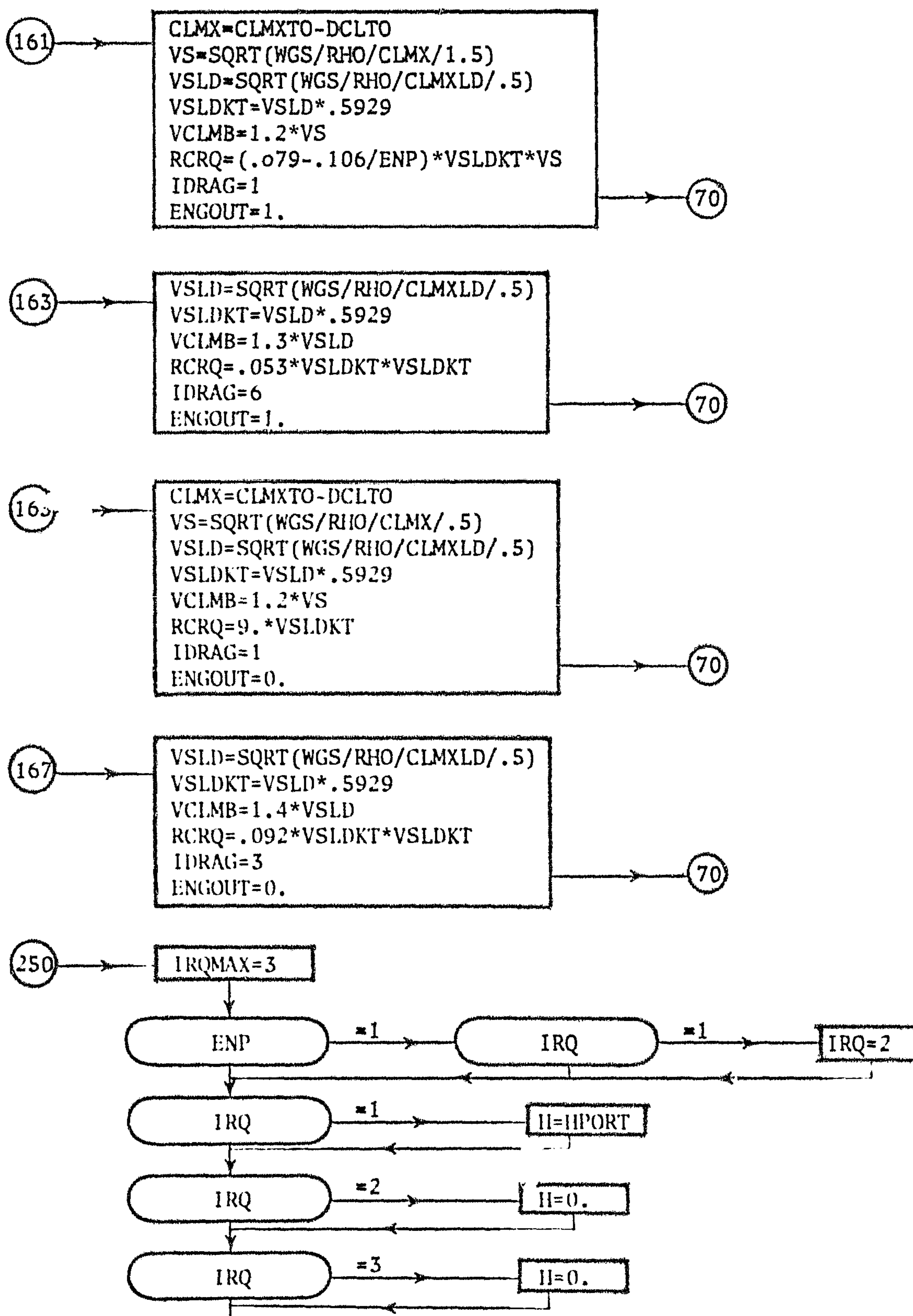

JTO
>0
1005
JRC
=0
DRGX=DRG
905
TN=DRG+WCR*RCCRU/(V*60.)
FN=TN/ENP
FNCRU=FN
ISEGX=G
PCPOWR=PCPCR
PCRPM=PCRCR
CALL ENGINE(FN,SFC,SFN,WFR,FAR,POCRU,TOCRU,SMN,HN,3)
KFPTCH
=0
PCPOWR
≤1
PCRPM
≤1
HPMSLS=HPMSLS*PCPOWR
PCPOWR=1.
DPROP=DPROP+1.
TIPSPD=XNMAX*DPROP*GRATIO
*3.1416/60.
9
TIPSPD
>TSPDMX
TIPSPD=TSPDMX
DPROP1=DROP
HPMSL1=HPMSLS
HPQDSK=HPMSLS/(.786*DROP*DROP)
GRATIO=TIPSPD*60./XNMAX/
DPROP/3.1416
JENGSZ
<1
100
JENGSZ
≤2
JC=0
JX=0
F=1.05
FF=1.01
ERRTC=1.
HX=H
KSIZE=1
IDCX=IDC
IDC=99
KWRITE=-1
50
JFPTCH
>0
KFPTCH=1
12
ICOND=0
ISEG=1
CALL PERFM(ISEG,ICOND,IFLY)

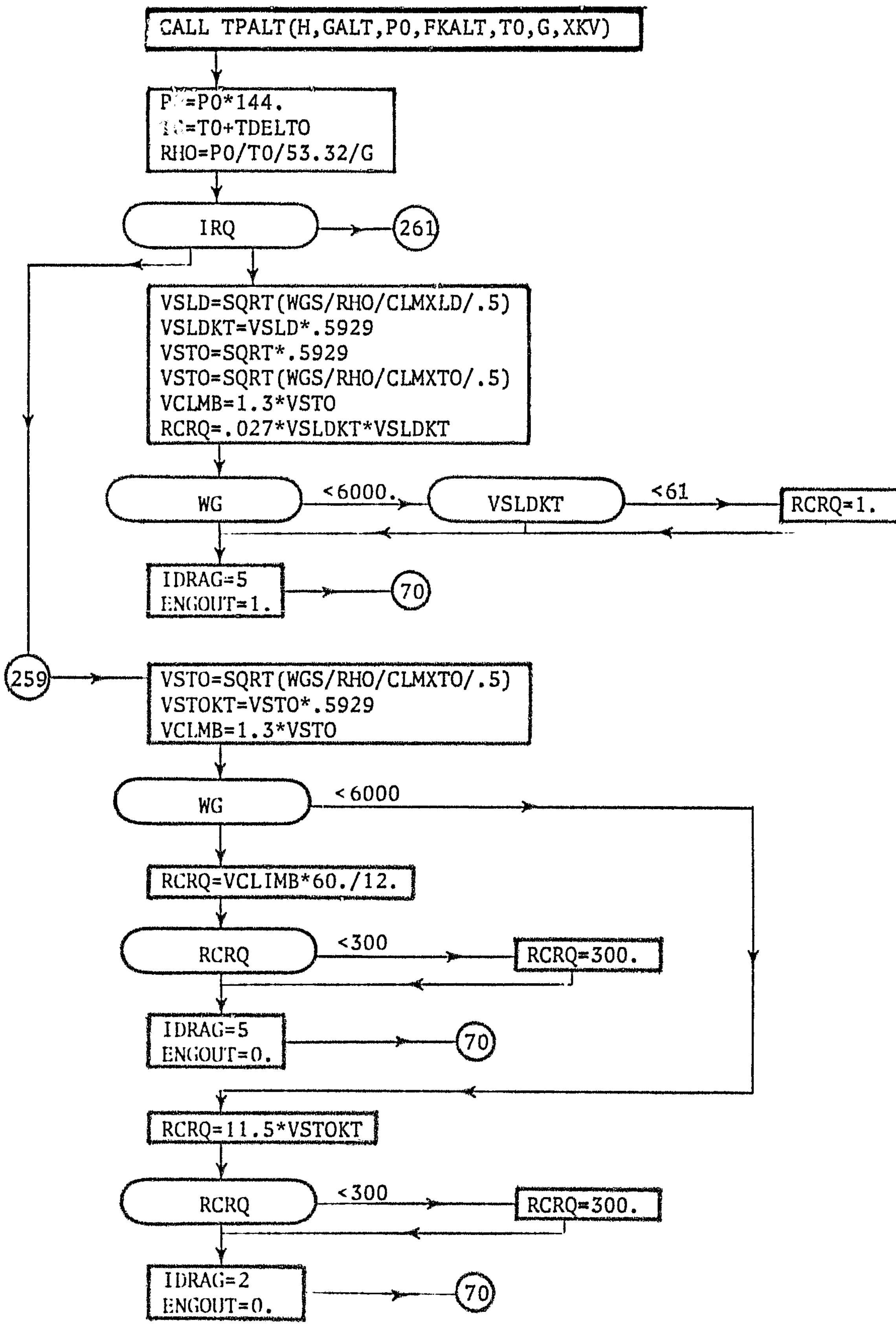

KSIZE
=2
JTO=1
ERRM1=ERRTO
ERRTO=(XTO-XTORQ)/XTORQ
AA=ABS(ERRTO)
KSIZE=3
DPROP2=DPROP1
HPMSL2=HPMSL1
H=HX
IDC=IDCX
KWRITE
=0
WRITE(6)XTO,
XTORQ,DPROP,
HPMSLS
JENGSZ
>1
100
AA
<.005
JX
>0
CALL ITRMHW(ERRTO,ERRM1,HPMSLS,F,FF,JX,JC)
JSIZE
=1
ADISK=HPMSLS/HPQDSK
DPROP=SQRT(ADISK/.786)
JC
>12
WRITE(6)ERRTO,
ERRM1,DPROP,HPMSLS
12
120
KSIZE=4
DPROP2=DPROP
HPMSL2=HPMSLS
H=HX
IDC=IDCX
JENGSZ
=1
100

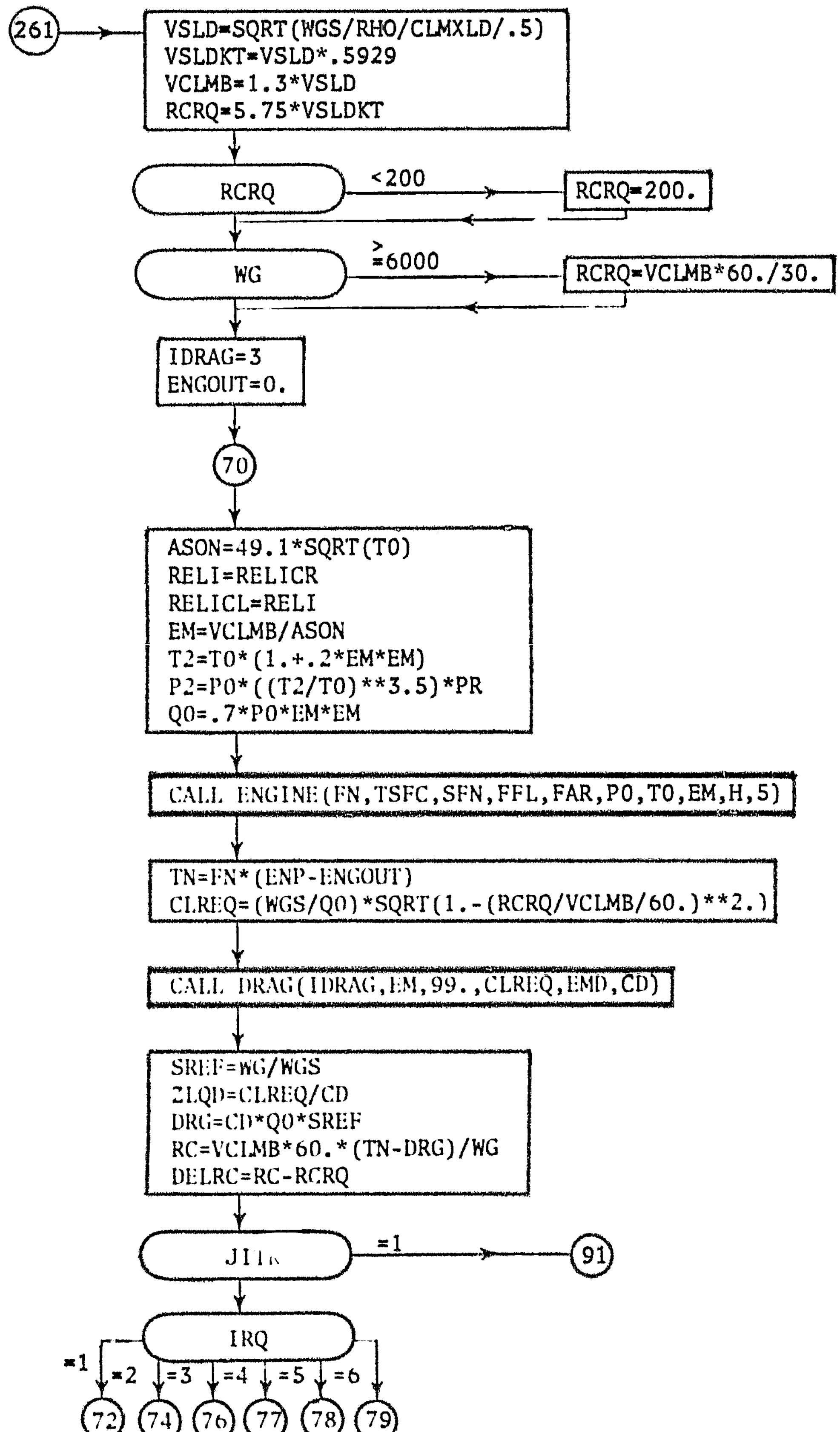

IRQ=1
JITR=0
XDELRC=0.
ISEGX=2
JFPTCH
>0
KFPTCH=1
ENP
=1
IRQ
=1
IPART=3
IPART
=3
250
=1
=2
150
IRQMAX=5
IRQ
=1
H=HPORT
IRQ
=2
H=HPORT+250.
IRQ
=3
H=HPORT+1500.
IRQ
=4
H=HPORT
IRQ
=5
H=HPORT
CALL TPALT(H,GALT,PO,FKALT,TO,G,XKV)
PO=PO*144.
TO=TO+TDELTO
RHO=PO/TO/53.32/G
IRQ
=1
=2
=3
=4
=5
57
59
61
63
65

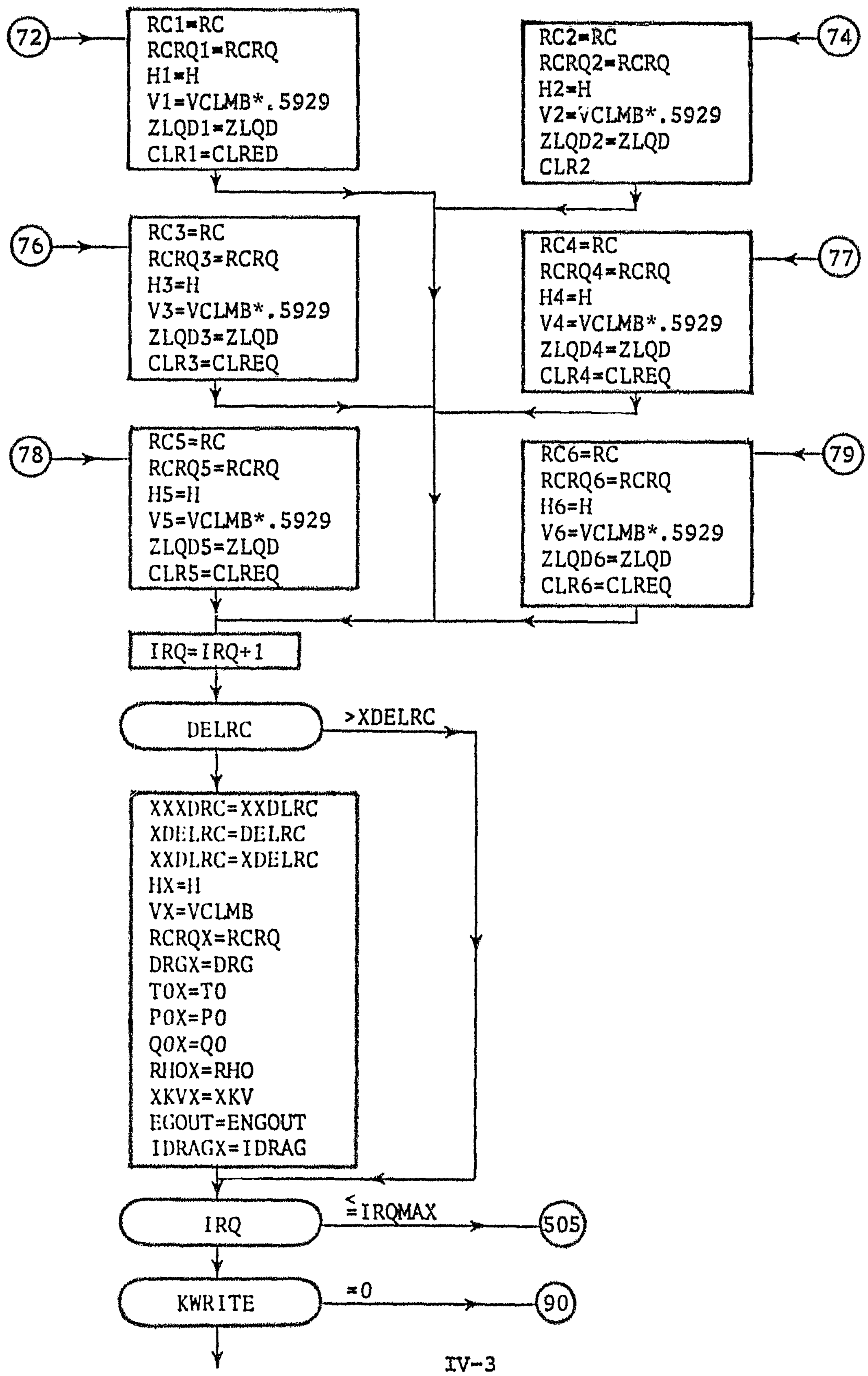

57
VSTO=SQRT(WGS/RHO/CLMXTO/.5)
VROT=VSTO+10./.5929
VLOF=5./.5929
VCLIMB=VLOF
RCRQ=1.
IDRAG=2
ENGOUT=1.
70
59
VSTO=SQRT(WGS/RHO/CLMXTO/.5)
VROT=VSTO+10./.5929
VLOF=VROT+5./.5929
VCLIMB=VLOF+45.
VCLMB
< (1.15*VSTO)
VCLMB=1.15*VSTO
RCRQ=(VCLMB*60.)*.024
IDRAG=5
ENGOUT=1
70
61
CLMX=CLMXTO-DCLTO
VS=SQRT(WGS/RHO/CLMX/.5)
VCLMB
< (1.25*VS)
VCLMB=1.25*VS
RCRQ=(VCLMB*60.)*.012
IDRAG=1
ENGOUT=1.
70
63
VSLD=SQRT(WGS/RHO/CLMXD/.5)
VCLMB=1.5*VSLD
RCRQ=(VCLMB*60.)*.021
IDRAG=8
CALL APPFLP(CLMXLD,DFLAP,IOK)
IOK
>0
IDRAG=3
ENGOUT=1
70

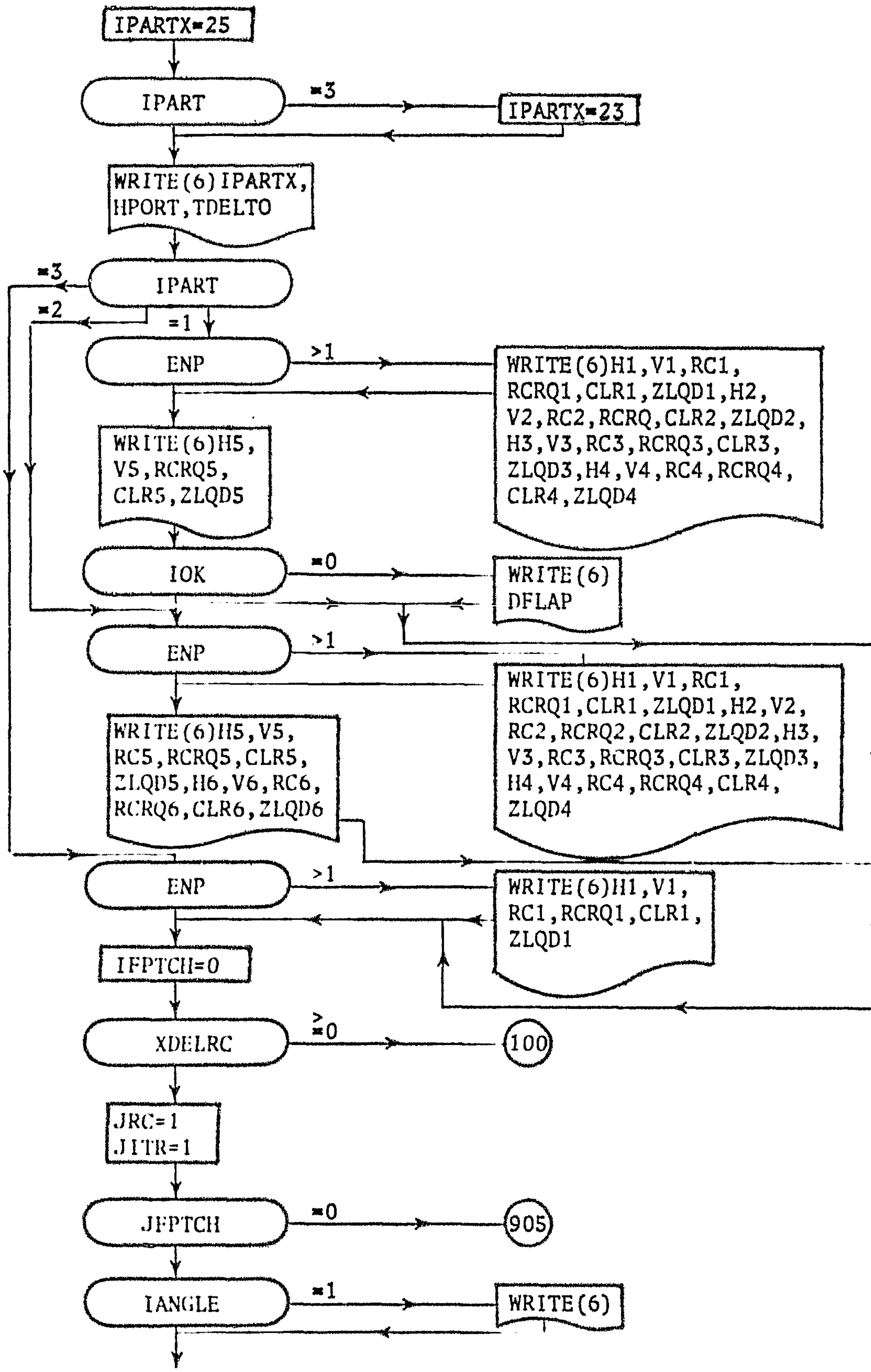

65
VSLD=SQRT(WGS/RHO/CLMXLD/.5)
VCLMB=1.3*VSLD
RCRQ=(VCLMB*60.)*.032
IDRAG=3
ENGOUT=0.
70
150
IRQMAX=6
IRQ
=1
H=HPORT
IRQ
=2
H=HPORT+250.
IRQ
=3
H=5000.
IRQ
=4
H=HPORT
IRQ
=5
H=5000.
IRQ
=6
H=HPORT
CALL TPALT(H,GALT,P0,FKALT,T0,G,XKV)
P0=P0*144.
T0=T0+TDELTO
RHO=P0/T0/53.32/G
IRQ
=1
=2
=3
=4
=5
=6
161
163
165
167
VSTO=SQRT(WGS/RHO/CLMXTO/.5)
VCLMB=1.2*VSTO
RCRQ=50.
IDRAG=2
ENGOUT=1.
70
VSTO=SQRT(WGS/RHO/CLMXTO/.5)
VSTOKT=VSTO*.5929
VCLMB=1.2*VSTO
RCRQ=.046*VSTOKT*VSTOKT
IDRAG=5
ENGOUT=1.
70

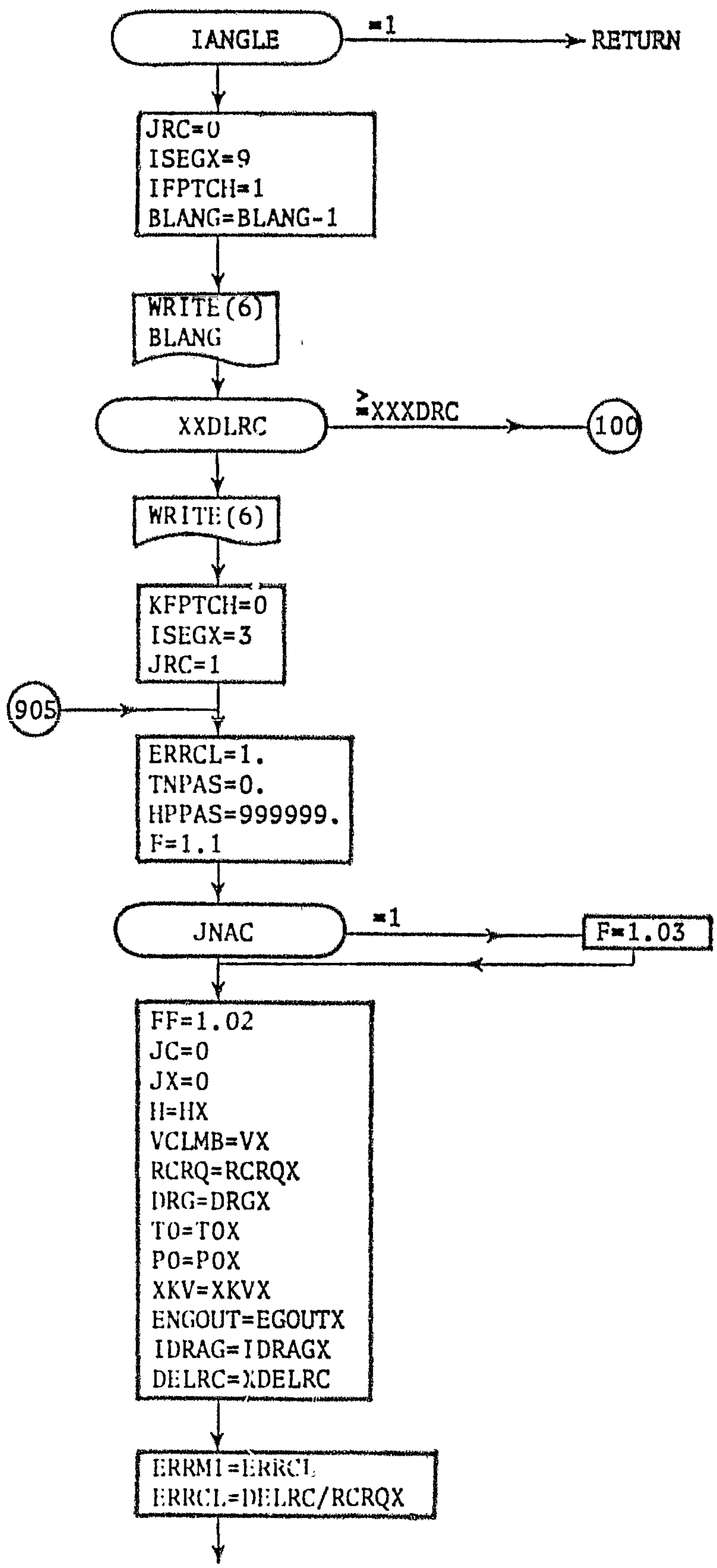

161
CLMX=CLMXTO-DCLTO
VS=SQRT(WGS/RHO/CLMX/1.5)
VSLD=SQRT(WGS/RHO/CLMXLD/.5)
VSLDKT=VSLD*.5929
VCLMB=1.2*VS
RCRQ=(.079-.106/ENP)*VSLDKT*VS
IDRAG=1
ENGOUT=1.
70
163
VSLD=SQRT(WGS/RHO/CLMXLD/.5)
VSLDKT=VSLD*.5929
VCLMB=1.3*VSLD
RCRQ=.053*VSLDKT*VSLDKT
IDRAG=6
ENGOUT=1.
70
165
CLMX=CLMXTO-DCLTO
VS=SQRT(WGS/RHO/CLMX/.5)
VSLD=SQRT(WGS/RHO/CLMXLD/.5)
VSLDKT=VSLD*.5929
VCLMB=1.2*VS
RCRQ=9.*VSLDKT
IDRAG=1
ENGOUT=0.
70
167
VSLD=SQRT(WGS/RHO/CLMXLD/.5)
VSLDKT=VSLD*.5929
VCLMB=1.4*VSLD
RCRQ=.092*VSLDKT*VSLDKT
IDRAG=3
ENGOUT=0.
70
250
IRQMAX=3
ENP
=1
IRQ
=1
IRQ=2
IRQ
=1
II=IIPORT
IRQ
=2
II=0.
IRQ
=3
II=0.

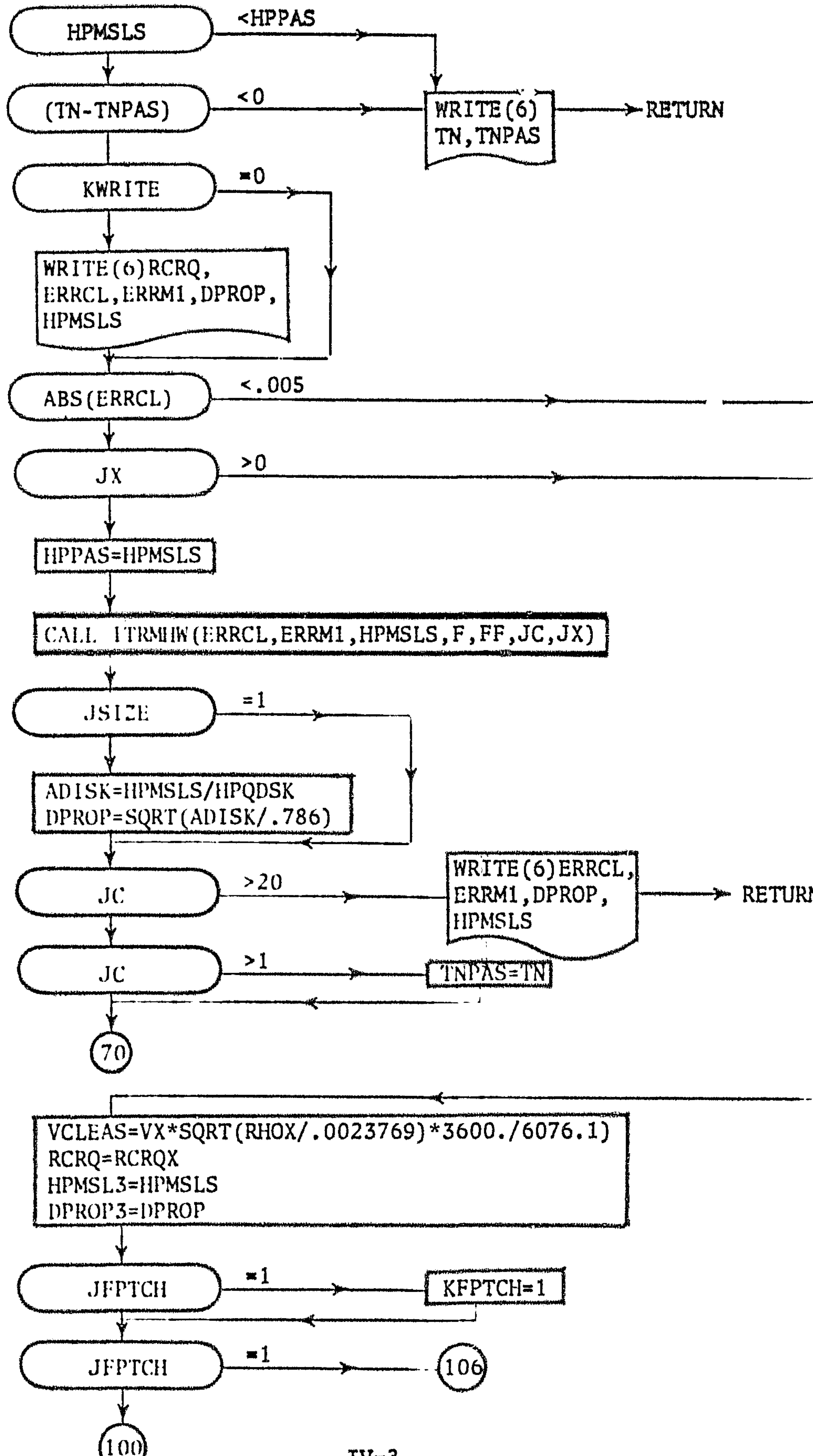

CALL TPALT(H,GALT,P0,FKALT,T0,G,XKV)
P0=P0*144.
T0=T0+TDELTO
RHO=P0/T0/53.32/G
IRQ
261
VSLD=SQRT(WGS/RHO/CLMXLD/.5)
VSLDKT=VSLD*.5929
VSTO=SQRT*.5929
VSTO=SQRT(WGS/RHO/CLMXTO/.5)
VCLMB=1.3*VSTO
RCRQ=.027*VSLDKT*VSLDKT
WG
<6000.
VSLDKT
<61
RCRQ=1.
IDRAG=5
ENGOUT=1.
70
259
VSTO=SQRT(WGS/RHO/CLMXTO/.5)
VSTOKT=VSTO*.5929
VCLMB=1.3*VSTO
WG
<6000
RCRQ=VCLIMB*60./12.
RCRQ
<300
RCRQ=300.
IDRAG=5
ENGOUT=0.
70
RCRQ=11.5*VSTOKT
RCRQ
<300
RCRQ=300.
IDRAG=2
ENGOUT=0.
70

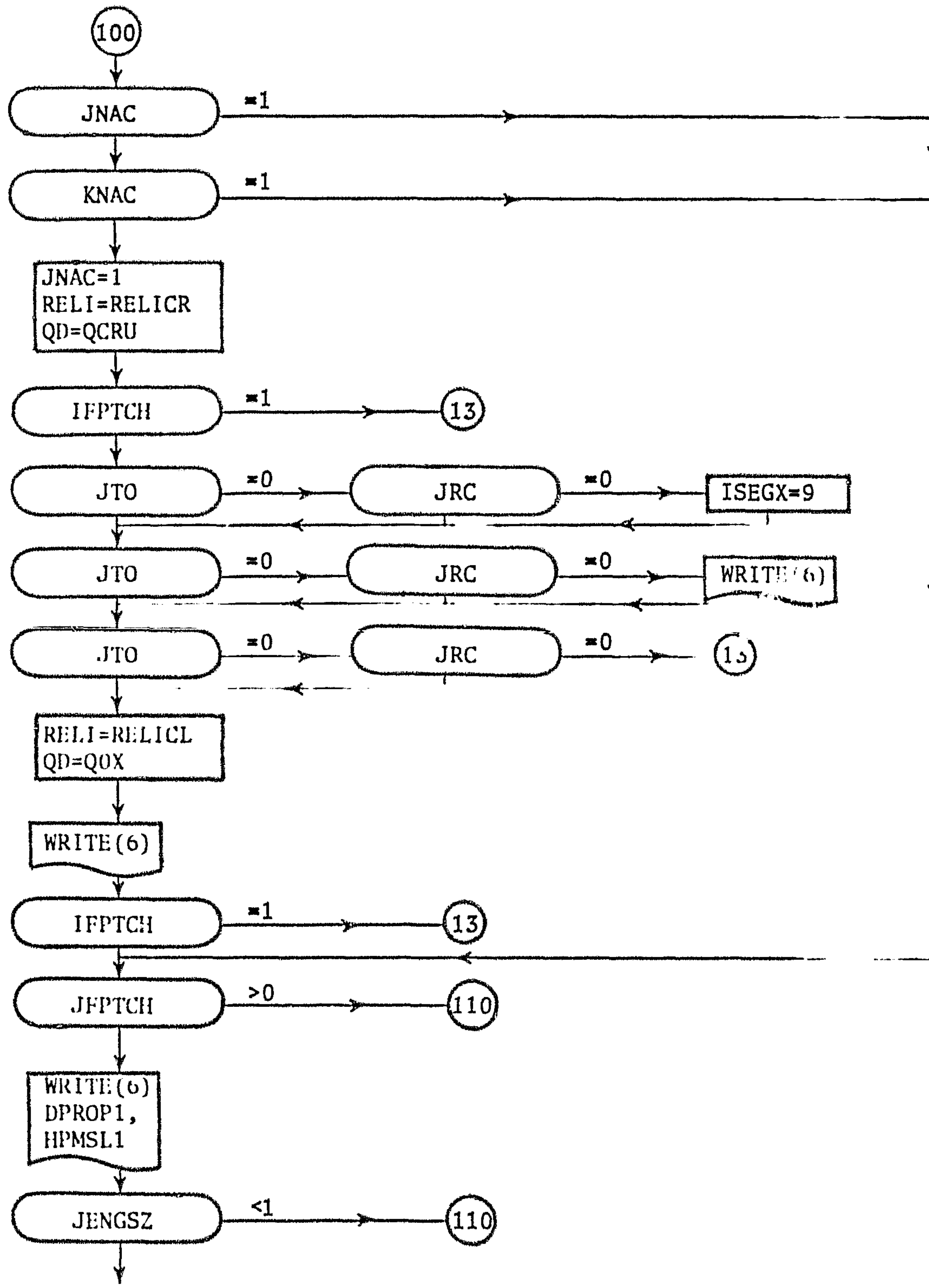

261
VSLD=SQRT(WGS/RHO/CLMXLD/.5)
VSLDKT=VSLD*.5929
VCLMB=1.3*VSLD
RCRQ=5.75*VSLDKT
RCRQ
<200
RCRQ=200.
WG
≥6000
RCRQ=VCLMB*60./30.
IDRAG=3
ENGOUT=0.
70
ASON=49.1*SQRT(T0)
RELI=RELICR
RELICL=RELI
EM=VCLMB/ASON
T2=T0*(1.+.2*EM*EM)
P2=P0*((T2/T0)**3.5)*PR
Q0=.7*P0*EM*EM
CALL ENGINE(FN,TSFC,SFN,FFL,FAR,P0,T0,EM,H,5)
TN=FN*(ENP-ENGOUT)
CLREQ=(WGS/Q0)*SQRT(1.-(RCRQ/VCLMB/60.)**2.)
CALL DRAG(IDRAG,EM,99.,CLREQ,EMD,CD)
SREF=WG/WGS
ZLQD=CLREQ/CD
DRG=CD*Q0*SREF
RC=VCLMB*60.*(TN-DRG)/WG
DELRC=RC-RCRQ
JITR
=1
91
IRQ
=1
=2
=3
=4
=5
=6
72
74
76
77
78
79

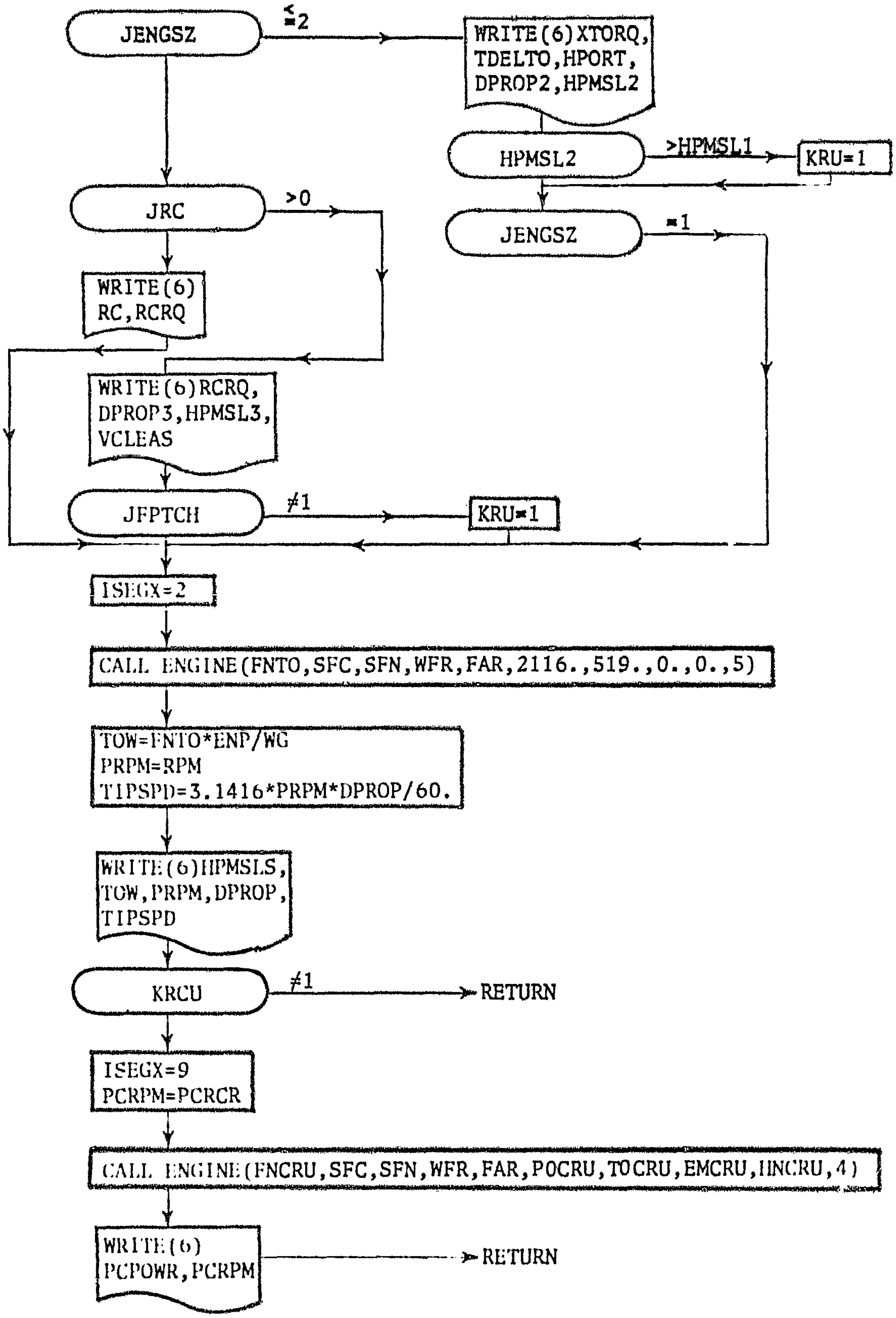

72
RC1=RC
RCRQ1=RCRQ
H1=H
V1=VCLMB*.5929
ZLQD1=ZLQD
CLR1=CLRED
74
RC2=RC
RCRQ2=RCRQ
H2=H
V2=VCLMB*.5929
ZLQD2=ZLQD
CLR2
76
RC3=RC
RCRQ3=RCRQ
H3=H
V3=VCLMB*.5929
ZLQD3=ZLQD
CLR3=CLREQ
77
RC4=RC
RCRQ4=RCRQ
H4=H
V4=VCLMB*.5929
ZLQD4=ZLQD
CLR4=CLREQ
78
RC5=RC
RCRQ5=RCRQ
H5=H
V5=VCLMB*.5929
ZLQD5=ZLQD
CLR5=CLREQ
79
RC6=RC
RCRQ6=RCRQ
H6=H
V6=VCLMB*.5929
ZLQD6=ZLQD
CLR6=CLREQ
IRQ=IRQ+1
DELRC
>XDELRC
XXXDRC=XXDLRC
XDELRC=DELRC
XXDLRC=XDELRC
HX=H
VX=VCLMB
RCRQX=RCRQ
DRGX=DRG
TOX=TO
POX=PO
QOX=QO
RHOX=RHO
XKVX=XKV
EGOUT=ENGOUT
IDRAGX=IDRAG
IRQ
≤IRQMAX
505
KWRITE
=0
90


IPARTX=25
IPART
=3
IPARTX=23
WRITE(6)IPARTX, HPORT,TDELTO
IPART
=3
=2
=1
ENP
>1
WRITE(6)H1,V1,RC1, RCRQ1,CLR1,ZLQD1,H2, V2,RC2,RCRQ,CLR2,ZLQD2, H3,V3,RC3,RCRQ3,CLR3, ZLQD3,H4,V4,RC4,RCRQ4, CLR4,ZLQD4
WRITE(6)H5, V5,RCRQ5, CLR5,ZLQD5
IOK
=0
WRITE(6) DFLAP
ENP
>1
WRITE(6)H1,V1,RC1, RCRQ1,CLR1,ZLQD1,H2,V2, RC2,RCRQ2,CLR2,ZLQD2,H3, V3,RC3,RCRQ3,CLR3,ZLQD3, H4,V4,RC4,RCRQ4,CLR4, ZLQD4
WRITE(6)H5,V5, RC5,RCRQ5,CLR5, ZLQD5,H6,V6,RC6, RCRQ6,CLR6,ZLQD6
ENP
>1
WRITE(6)H1,V1, RC1,RCRQ1,CLR1, ZLQD1
IFPTCH=0
XDELRC
≥0
100
JRC=1
JITR=1
JFPTCH
=0
905
IANGLE
=1
WRITE(6)


IANGLE
=1
RETURN
JRC=0
ISEGX=9
IFPTCH=1
BLANG=BLANG-1
WRITE(6)
BLANG
XXDLRC
≥XXXDRC
100
WRITE(6)
KFPTCH=0
ISEGX=3
JRC=1
905
ERRCL=1.
TNPAS=0.
HPPAS=999999.
F=1.1
JNAC
=1
F=1.03
FF=1.02
JC=0
JX=0
H=HX
VCLMB=VX
RCRQ=RCRQX
DRG=DRGX
TO=TOX
PO=POX
XKV=XKVX
ENGOUT=EGOUTX
IDRAG=IDRAGX
DELRC=XDELRC
ERRM1=ERRCL
ERRCL=DELRC/RCRQX


HPMSLS
<HPPAS
(TN-TNPAS)
<0
WRITE(6)
TN,TNPAS
RETURN
KWRITE
=0
WRITE(6)RCRQ,
ERRCL,ERRM1,DPROP,
HPMSLS
ABS(ERRCL)
<.005
JX
>0
HPPAS=HPMSLS
CALL ITRMHW(ERRCL,ERRM1,HPMSLS,F,FF,JC,JX)
JSIZE
=1
ADISK=HPMSLS/HPQDSK
DPROP=SQRT(ADISK/.786)
JC
>20
WRITE(6)ERRCL,
ERRM1,DPROP,
HPMSLS
RETURN
JC
>1
TNPAS=TN
70
VCLEAS=VX*SQRT(RHOX/.0023769)*3600./6076.1)
RCRQ=RCRQX
HPMSL3=HPMSLS
DPROP3=DPROP
JFPTCH
=1
KFPTCH=1
JFPTCH
=1
106
100


100
JNAC
=1
KNAC
=1
JNAC=1
RELI=RELICR
QD=QCRU
IFPTCH
=1
13
JTO
=0
JRC
=0
ISEGX=9
JTO
=0
JRC
=0
WRITE(6)
JTO
=0
JRC
=0
RELI=RELICL
QD=QOX
WRITE(6)
IFPTCH
=1
13
JFPTCH
>0
110
WRITE(6)
DPROP1,
HPMSL1
JENGSZ
<1
110


JENGSZ
≤2
WRITE(6)XTORQ, TDELTO,HPORT, DPROP2,HPMSL2
HPMSL2
>HPMSL1
KRU=1
JENGSZ
=1
JRC
>0
WRITE(6) RC,RCRQ
WRITE(6)RCRQ, DPROP3,HPMSL3, VCLEAS
JFPTCH
≠1
KRU=1
ISEGX=2
CALL ENGINE(FNTO,SFC,SFN,WFR,FAR,2116.,519.,0.,0.,5)
TOW=FNTO*ENP/WG
PRPM=RPM
TIPSPD=3.1416*PRPM*DPROP/60.
WRITE(6)HPMSLS, TOW,PRPM,DPROP, TIPSPD
KRCU
≠1
RETURN
ISEGX=9
PCRPM=PCRCR
CALL ENGINE(FNCRU,SFC,SFN,WFR,FAR,POCRU,TOCRU,EMCRU,HNCRU,4)
WRITE(6) PCPOWR,PCRPM
RETURN

IV.3.2.4 Subroutine GEARBX, Gearbox Weight, Cost, and Noise. Subroutine GEARBX carries out gearbox weight, noise, and cost computations using the method of Section IV.1.3.3. No other subroutines are called by this routine. A detailed flow chart for subroutine GEARBX is presented in Figure IV.3.7.

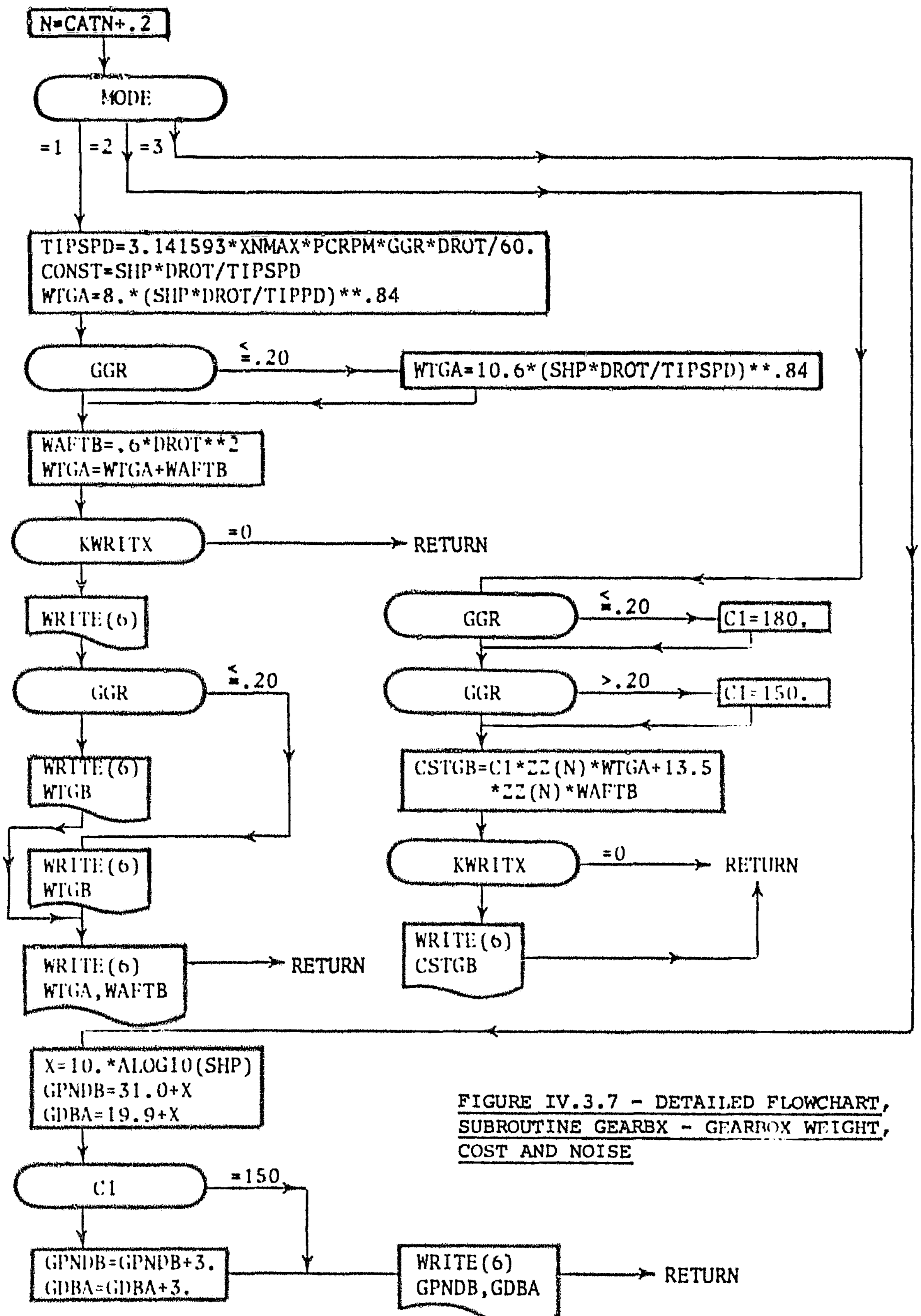


FIGURE IV.3.7 - DETAILED FLOWCHART, SUBROUTINE GEARBX - GEARBOX WEIGHT, COST AND NOISE

IV.3.2.5 <u>Subroutine PERFM, Propeller Performance.</u> Subroutine PERFM computes propeller performance by the method of Section IV.1.3.1. Calculations mainly involve interpolation in stored data using the utility routines BIV (Section I.1.3.4) and UNINT (Section I.1.3.17). A detailed flow chart for subroutine PERFM is presented in Figure IV.3.8.

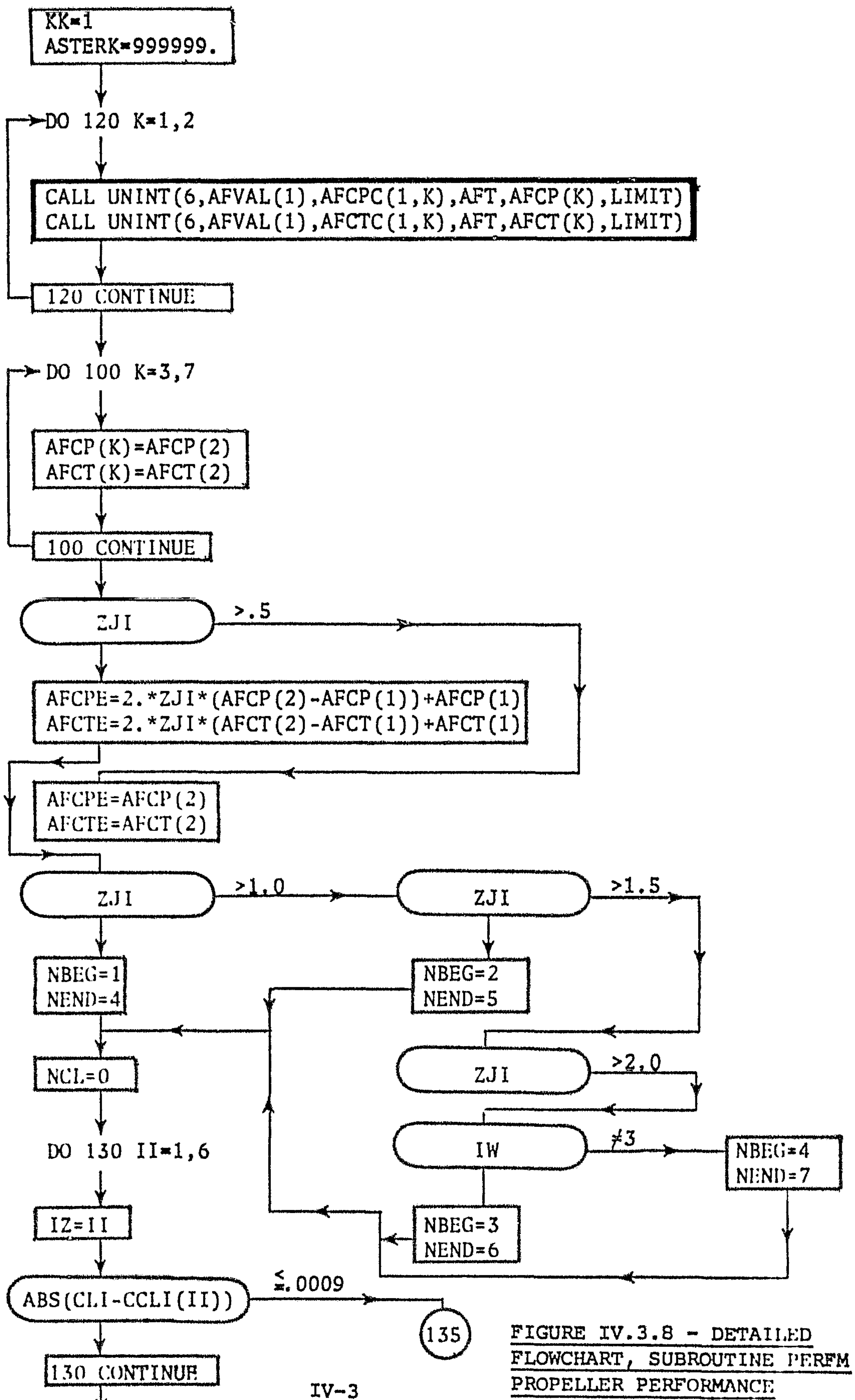
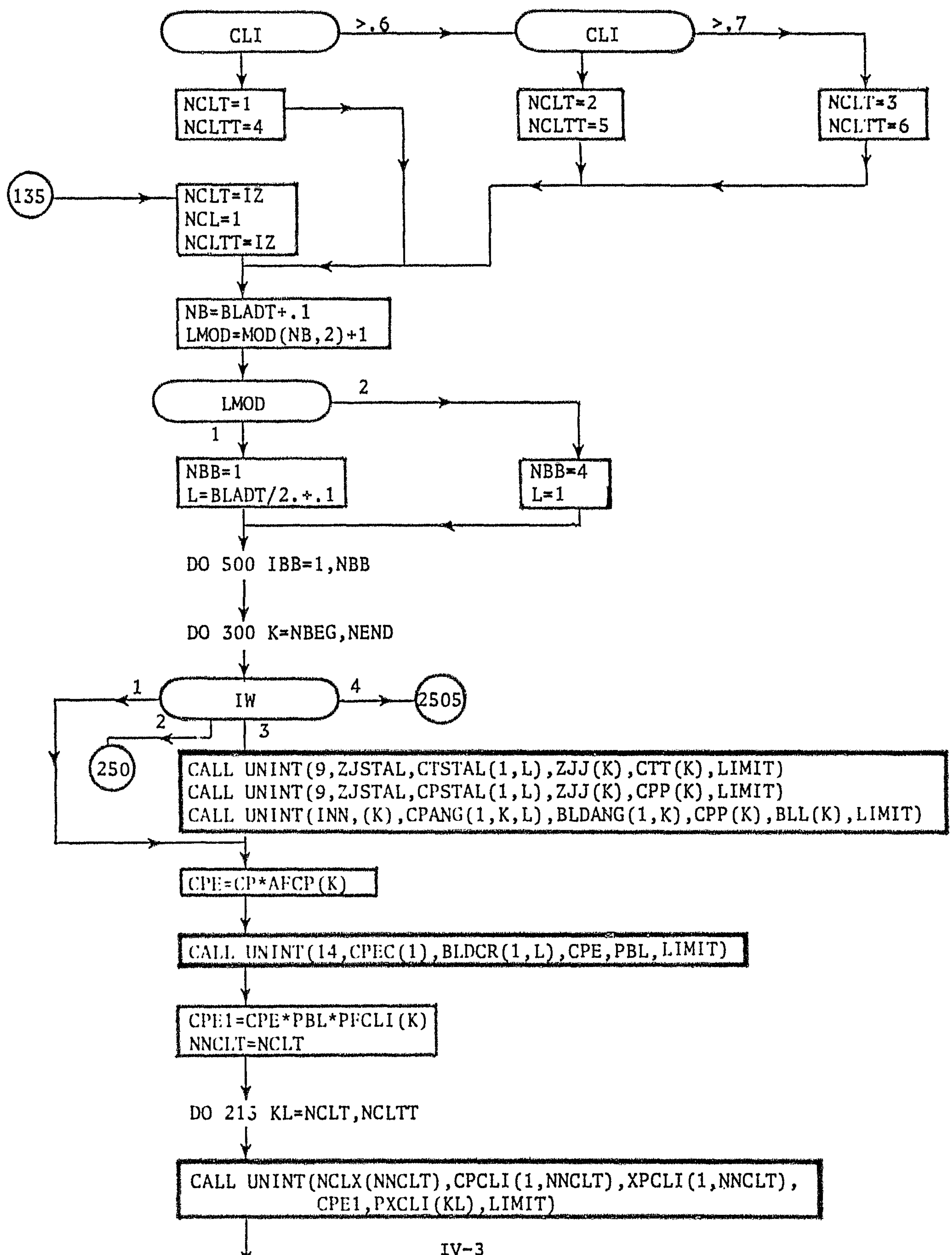
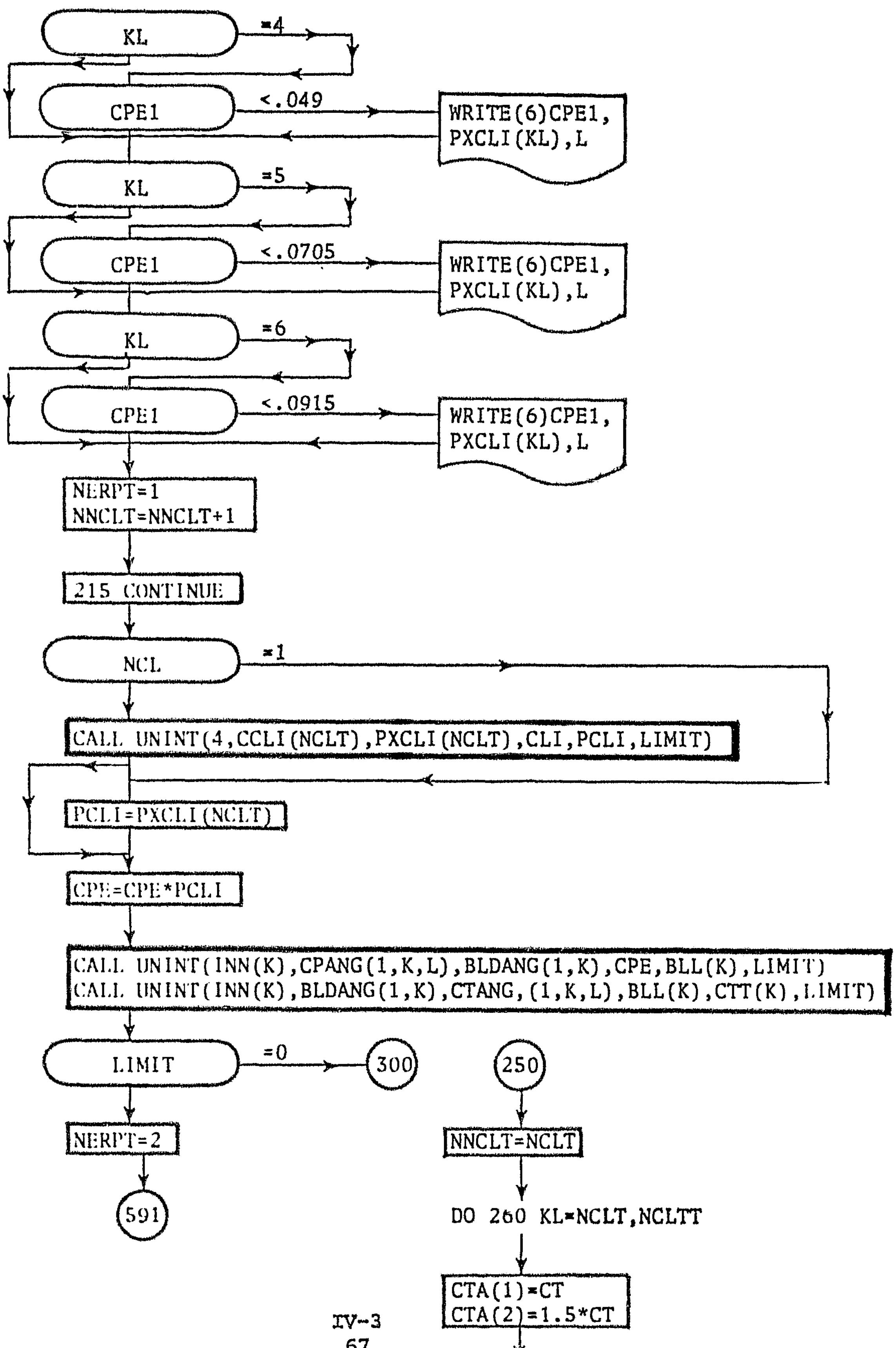
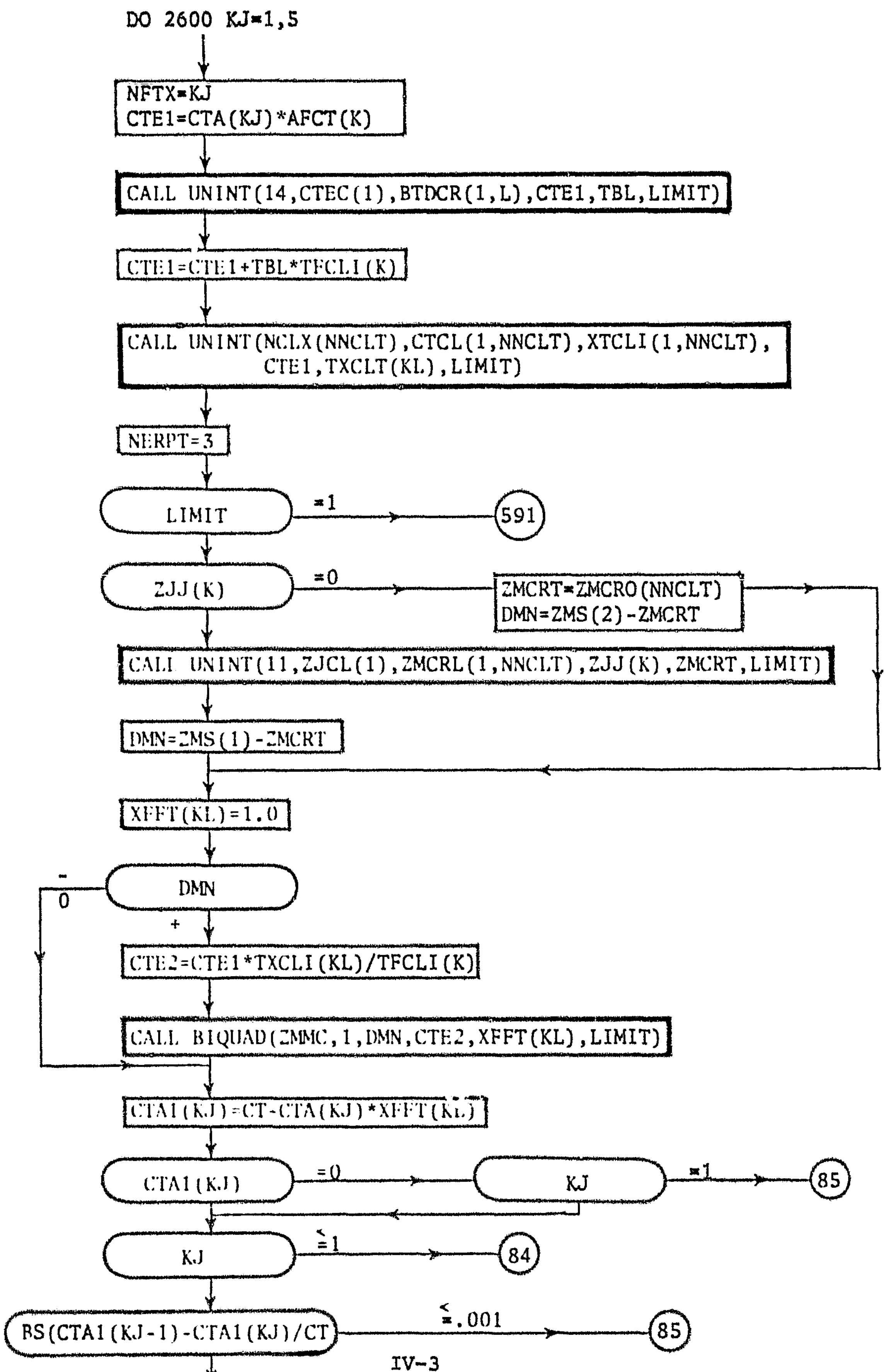
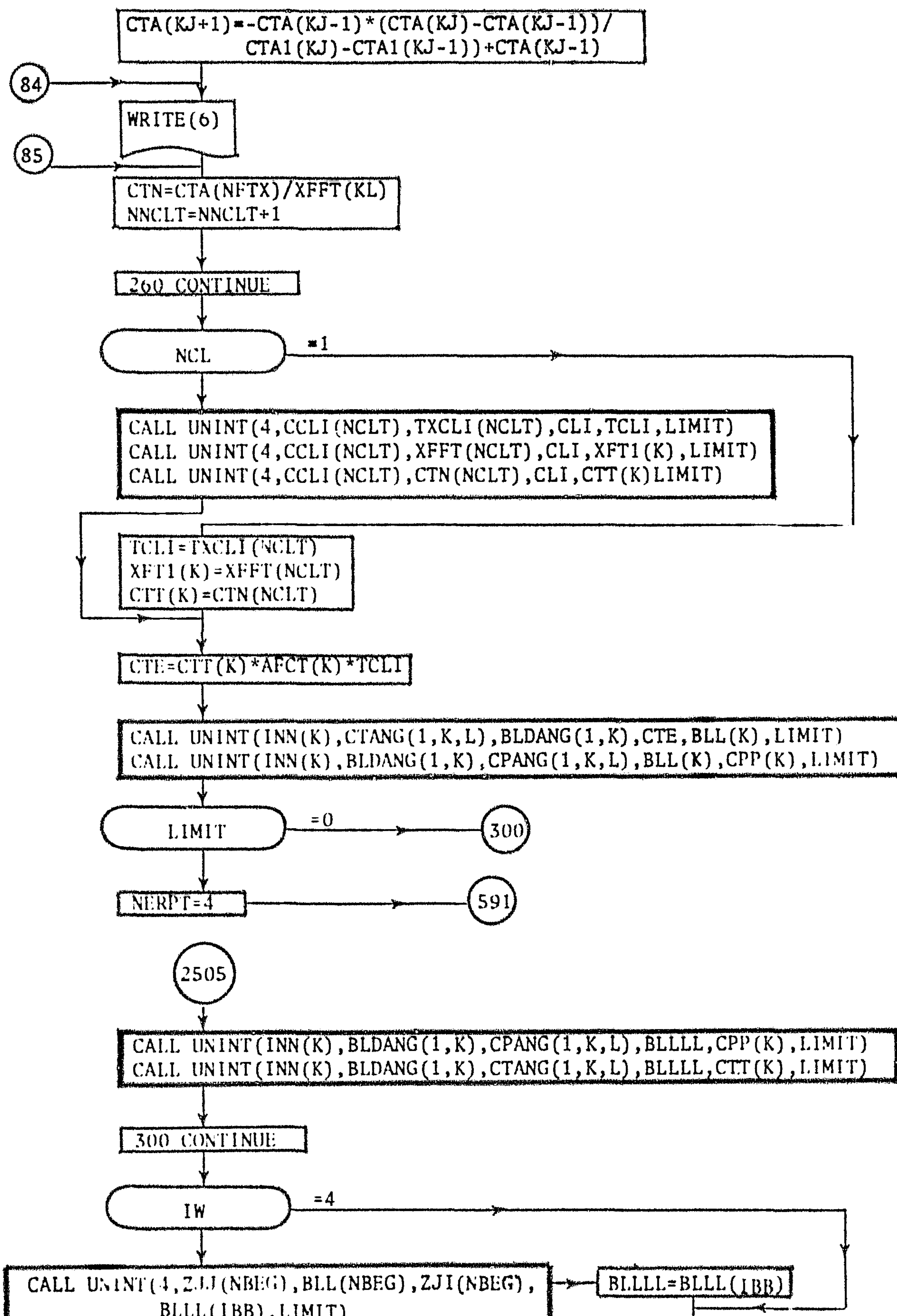


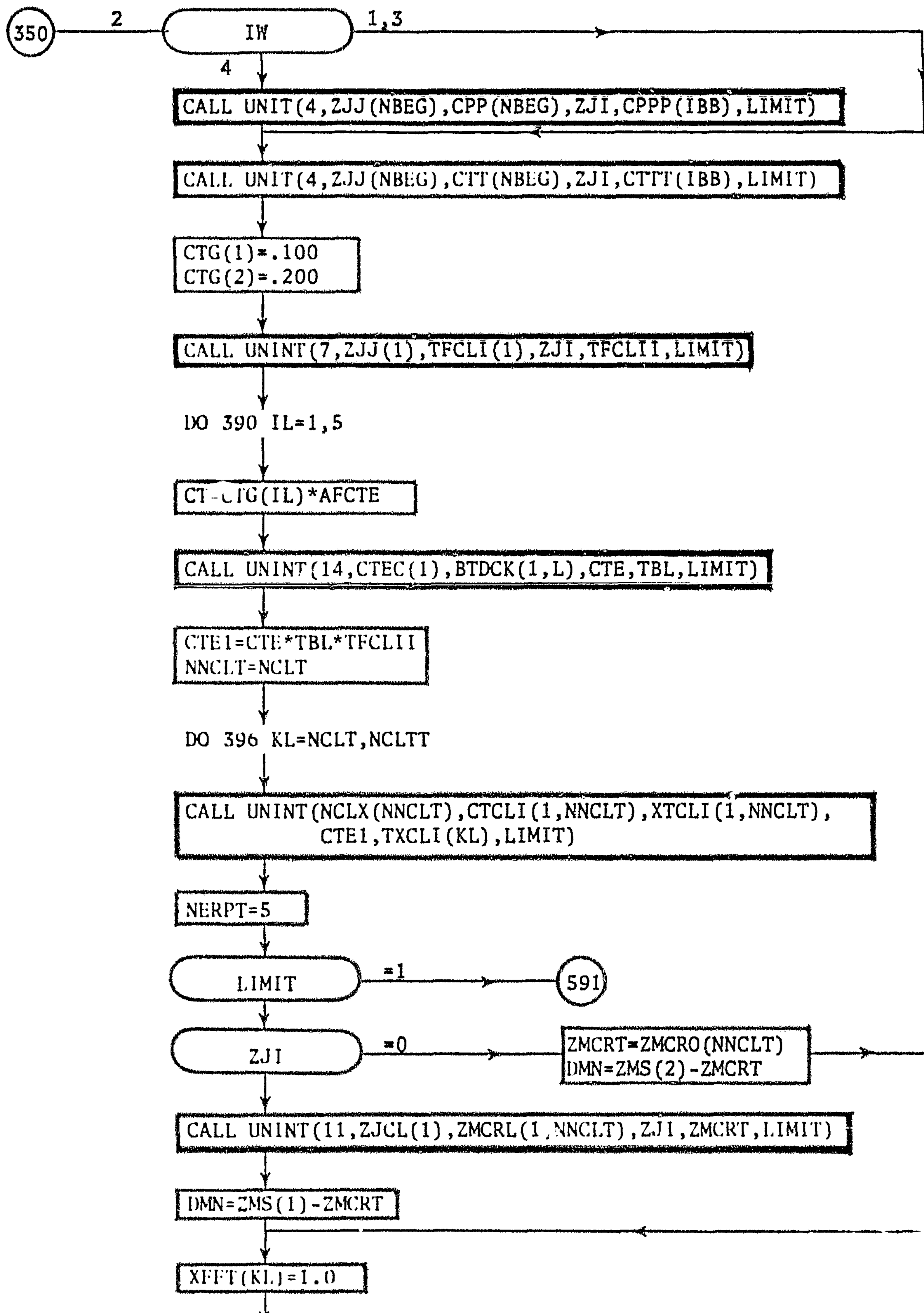
FIGURE IV.3.8 - DETAILED FLOWCHART, SUBROUTINE PERFM PROPELLER PERFORMANCE

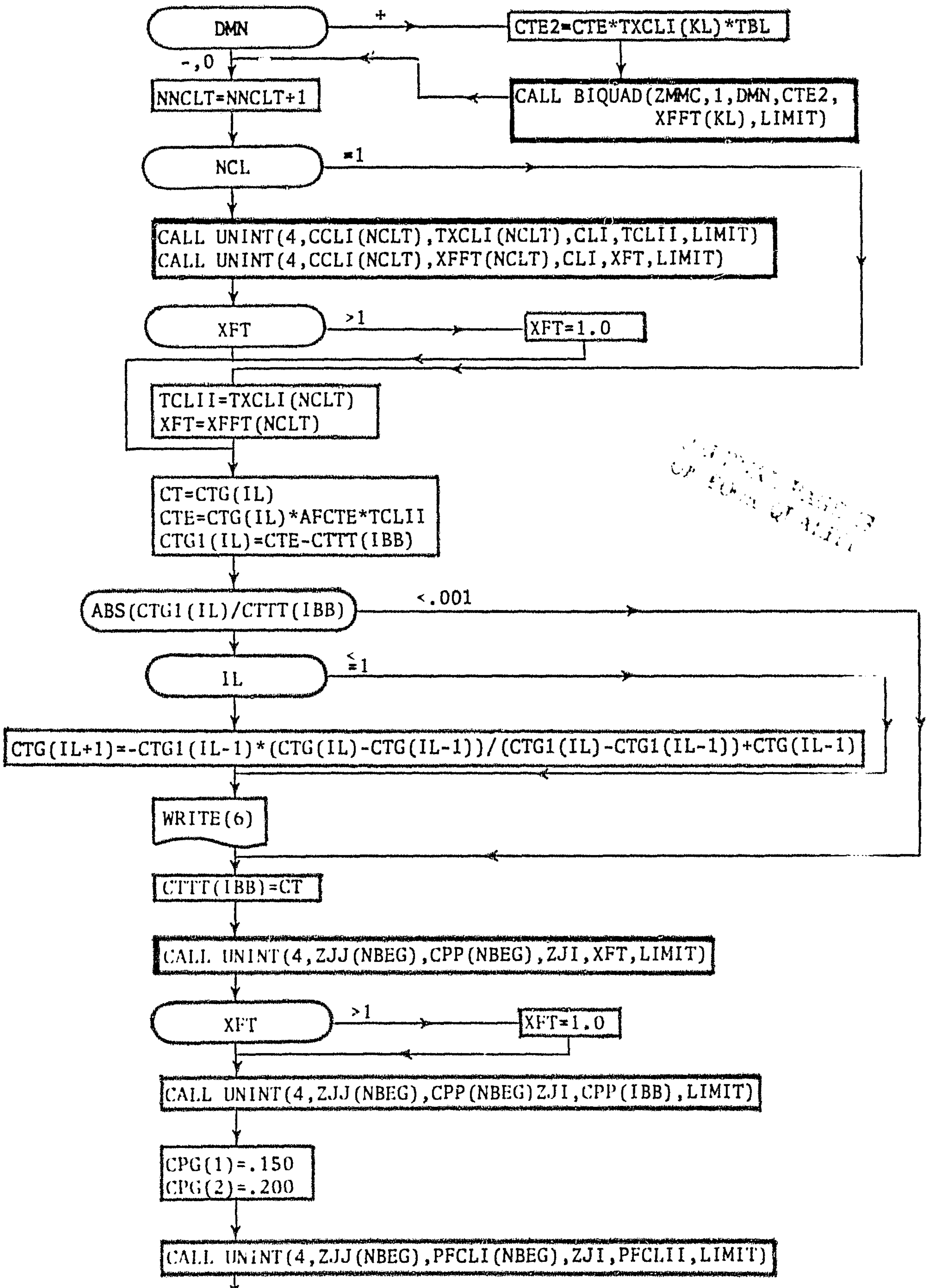

CLI
>.6
CLI
>.7
NCLT=1
NCLTT=4
NCLT=2
NCLTT=5
NCLT=3
NCLTT=6
135
NCLT=IZ
NCL=1
NCLTT=IZ
NB=BLADT+.1
LMOD=MOD(NB,2)+1
LMOD
2
1
NBB=1
L=BLADT/2.+.1
NBB=4
L=1
DO 500 IBB=1,NBB
DO 300 K=NBEG,NEND
IW
1
4
2505
2
3
250
CALL UNINT(9,ZJSTAL,CTSTAL(1,L),ZJJ(K),CTT(K),LIMIT)
CALL UNINT(9,ZJSTAL,CPSTAL(1,L),ZJJ(K),CPP(K),LIMIT)
CALL UNINT(INN,(K),CPANG(1,K,L),BLDANG(1,K),CPP(K),BLL(K),LIMIT)
CPE=CP*AFCP(K)
CALL UNINT(14,CPEC(1),BLDCR(1,L),CPE,PBL,LIMIT)
CPE1=CPE*PBL*PFCLI(K)
NNCLT=NCLT
DO 215 KL=NCLT,NCLTT
CALL UNINT(NCLX(NNCLT),CPCLI(1,NNCLT),XPCLI(1,NNCLT),
CPE1,PXCLI(KL),LIMIT)

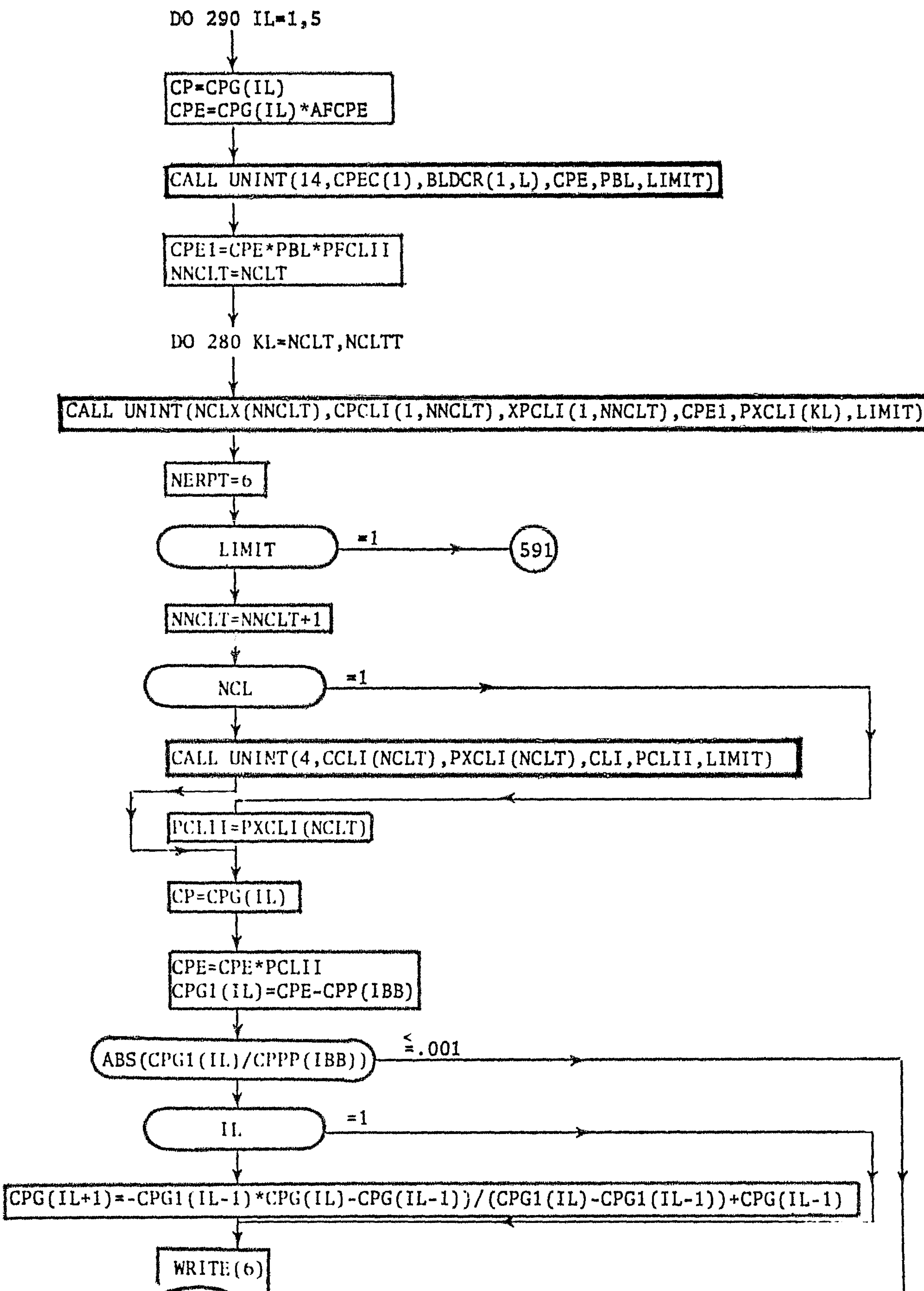

KL
=4
CPE1
<.049
WRITE(6)CPE1, PXCLI(KL),L
KL
=5
CPE1
<.0705
WRITE(6)CPE1, PXCLI(KL),L
KL
=6
CPE1
<.0915
WRITE(6)CPE1, PXCLI(KL),L
NERPT=1
NNCLT=NNCLT+1
215 CONTINUE
NCL
=1
CALL UNINT(4,CCLI(NCLT),PXCLI(NCLT),CLI,PCLI,LIMIT)
PCLI=PXCLI(NCLT)
CPE=CPE*PCLI
CALL UNINT(INN(K),CPANG(1,K,L),BLDANG(1,K),CPE,BLL(K),LIMIT)
CALL UNINT(INN(K),BLDANG(1,K),CTANG,(1,K,L),BLL(K),CTT(K),LIMIT)
LIMIT
=0
300
NERPT=2
591
250
NNCLT=NCLT
DO 260 KL=NCLT,NCLTT
CTA(1)=CT
CTA(2)=1.5*CT

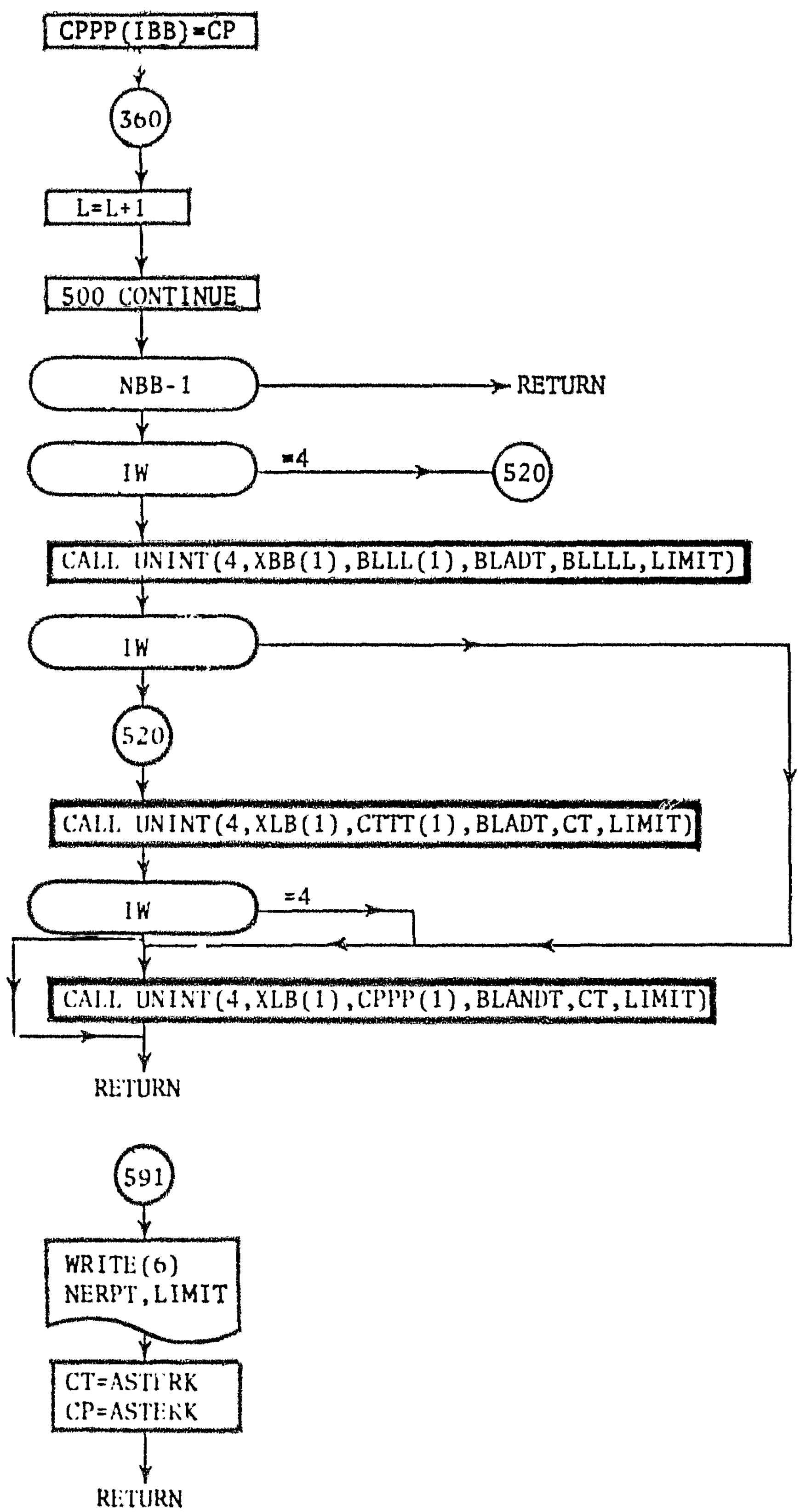

DO 2600 KJ=1,5
NFTX=KJ
CTE1=CTA(KJ)*AFCT(K)
CALL UNINT(14,CTEC(1),BTDCR(1,L),CTE1,TBL,LIMIT)
CTE1=CTE1+TBL*TFCLI(K)
CALL UNINT(NCLX(NNCLT),CTCL(1,NNCLT),XTCLI(1,NNCLT),
CTE1,TXCLT(KL),LIMIT)
NERPT=3
LIMIT
=1
591
ZJJ(K)
=0
ZMCRT=ZMCRO(NNCLT)
DMN=ZMS(2)-ZMCRT
CALL UNINT(11,ZJCL(1),ZMCRL(1,NNCLT),ZJJ(K),ZMCRT,LIMIT)
DMN=ZMS(1)-ZMCRT
XFFT(KL)=1.0
DMN
-
0
+
CTE2=CTE1*TXCLI(KL)/TFCLI(K)
CALL BIQUAD(ZMMC,1,DMN,CTE2,XFFT(KL),LIMIT)
CTA1(KJ)=CT-CTA(KJ)*XFFT(KL)
CTA1(KJ)
=0
KJ
=1
85
KJ
≦1
84
BS(CTA1(KJ-1)-CTA1(KJ)/CT
≦.001
85


CTA(KJ+1)=-CTA(KJ-1)*(CTA(KJ)-CTA(KJ-1))/
CTA1(KJ)-CTA1(KJ-1))+CTA(KJ-1)
84
WRITE(6)
85
CTN=CTA(NFTX)/XFFT(KL)
NNCLT=NNCLT+1
260 CONTINUE
NCL
=1
CALL UNINT(4,CCLI(NCLT),TXCLI(NCLT),CLI,TCLI,LIMIT)
CALL UNINT(4,CCLI(NCLT),XFFT(NCLT),CLI,XFT1(K),LIMIT)
CALL UNINT(4,CCLI(NCLT),CTN(NCLT),CLI,CTT(K)LIMIT)
TCLI=TXCLI(NCLT)
XFT1(K)=XFFT(NCLT)
CTT(K)=CTN(NCLT)
CTE=CTT(K)*AFCT(K)*TCLI
CALL UNINT(INN(K),CTANG(1,K,L),BLDANG(1,K),CTE,BLL(K),LIMIT)
CALL UNINT(INN(K),BLDANG(1,K),CPANG(1,K,L),BLL(K),CPP(K),LIMIT)
LIMIT
=0
300
NERPT=4
591
2505
CALL UNINT(INN(K),BLDANG(1,K),CPANG(1,K,L),BLLLL,CPP(K),LIMIT)
CALL UNINT(INN(K),BLDANG(1,K),CTANG(1,K,L),BLLLL,CTT(K),LIMIT)
300 CONTINUE
IW
=4
CALL UNINT(4,ZJJ(NBEG),BLL(NBEG),ZJI(NBEG),
BLLL(IBB),LIMIT)
BLLLL=BLLL(IBB)


350
2
IW
1,3
4
CALL UNIT(4,ZJJ(NBEG),CPP(NBEG),ZJI,CPPP(IBB),LIMIT)
CALL UNIT(4,ZJJ(NBEG),CTT(NBEG),ZJI,CTTT(IBB),LIMIT)
CTG(1)=.100
CTG(2)=.200
CALL UNINT(7,ZJJ(1),TFCLI(1),ZJI,TFCLII,LIMIT)
DO 390 IL=1,5
CT=CTG(IL)*AFCTE
CALL UNINT(14,CTEC(1),BTDCK(1,L),CTE,TBL,LIMIT)
CTE1=CTE*TBL*TFCLII
NNCLT=NCLT
DO 396 KL=NCLT,NCLTT
CALL UNINT(NCLX(NNCLT),CTCLI(1,NNCLT),XTCLI(1,NNCLT),
CTE1,TXCLI(KL),LIMIT)
NERPT=5
LIMIT
=1
591
ZJI
=0
ZMCRT=ZMCRO(NNCLT)
DMN=ZMS(2)-ZMCRT
CALL UNINT(11,ZJCL(1),ZMCRL(1,NNCLT),ZJI,ZMCRT,LIMIT)
DMN=ZMS(1)-ZMCRT
XEFT(KL)=1.0


DMN
+
-,0
CTE2=CTE*TXCLI(KL)*TBL
CALL BIQUAD(ZMMC,1,DMN,CTE2,
XFFT(KL),LIMIT)
NNCLT=NNCLT+1
NCL
=1
CALL UNINT(4,CCLI(NCLT),TXCLI(NCLT),CLI,TCLII,LIMIT)
CALL UNINT(4,CCLI(NCLT),XFFT(NCLT),CLI,XFT,LIMIT)
XFT
>1
XFT=1.0
TCLII=TXCLI(NCLT)
XFT=XFFT(NCLT)
CT=CTG(IL)
CTE=CTG(IL)*AFCTE*TCLII
CTG1(IL)=CTE-CTTT(IBB)
ABS(CTG1(IL)/CTTT(IBB)
<.001
IL
≤1
CTG(IL+1)=-CTG1(IL-1)*(CTG(IL)-CTG(IL-1))/(CTG1(IL)-CTG1(IL-1))+CTG(IL-1)
WRITE(6)
CTTT(IBB)=CT
CALL UNINT(4,ZJJ(NBEG),CPP(NBEG),ZJI,XFT,LIMIT)
XFT
>1
XFT=1.0
CALL UNINT(4,ZJJ(NBEG),CPP(NBEG)ZJI,CPP(IBB),LIMIT)
CPG(1)=.150
CPG(2)=.200
CALL UNINT(4,ZJJ(NBEG),PFCLI(NBEG),ZJI,PFCLII,LIMIT)


DO 290 IL=1,5
CP=CPG(IL)
CPE=CPG(IL)*AFCPE
CALL UNINT(14,CPEC(1),BLDCR(1,L),CPE,PBL,LIMIT)
CPE1=CPE*PBL*PFCLII
NNCLT=NCLT
DO 280 KL=NCLT,NCLTT
CALL UNINT(NCLX(NNCLT),CPCLI(1,NNCLT),XPCLI(1,NNCLT),CPE1,PXCLI(KL),LIMIT)
NERPT=6
LIMIT
=1
591
NNCLT=NNCLT+1
NCL
=1
CALL UNINT(4,CCLI(NCLT),PXCLI(NCLT),CLI,PCLII,LIMIT)
PCLII=PXCLI(NCLT)
CP=CPG(IL)
CPE=CPE*PCLII
CPG1(IL)=CPE-CPP(IBB)
ABS(CPG1(IL)/CPPP(IBB))
≤.001
IL
=1
CPG(IL+1)=-CPG1(IL-1)*CPG(IL)-CPG(IL-1))/(CPG1(IL)-CPG1(IL-1))+CPG(IL-1)
WRITE(6)


CPPP(IBB)=CP
360
L=L+1
500 CONTINUE
NBB-1
RETURN
IW
=4
520
CALL UNINT(4,XBB(1),BLLL(1),BLADT,BLLLL,LIMIT)
IW
520
CALL UNINT(4,XLB(1),CTTT(1),BLADT,CT,LIMIT)
IW
=4
CALL UNINT(4,XLB(1),CPPP(1),BLANDT,CT,LIMIT)
RETURN
591
WRITE(6)
NERPT,LIMIT
CT=ASTERK
CP=ASTERK
RETURN

IV.3.2.6 <u>Subroutine PNOYS, Propeller Driven Aircraft Noise Controlling Routine</u>. Subroutine PNOYS controls the propeller driven aircraft noise calculations as discussed in Section IV.1.3.6. Routines called by PNOYS include subroutine ENGINE for engine performance (Section IV.1.2.2); subroutine GEARBX for gear box characteristics (Section IV.1.3.3); Subroutine ZNENG for engine noise characteristics (Section IV.1.3.7); subroutine TPALT for atmospheric properties (Section I.1.3.15), and subroutine ASPEED.

A detailed flow chart for subroutine PNOYS is presented in Figure IV.3.9.

PNOYS

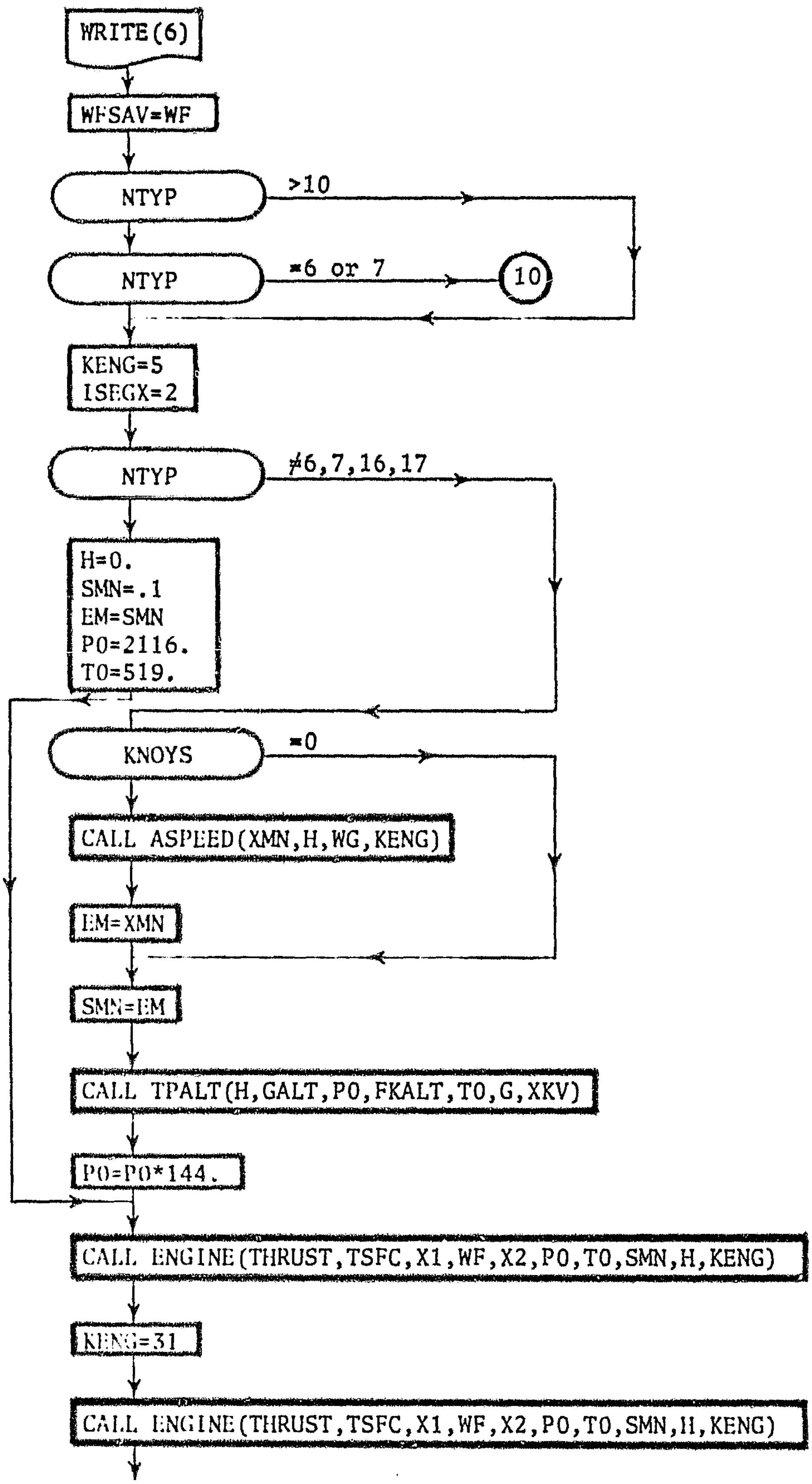
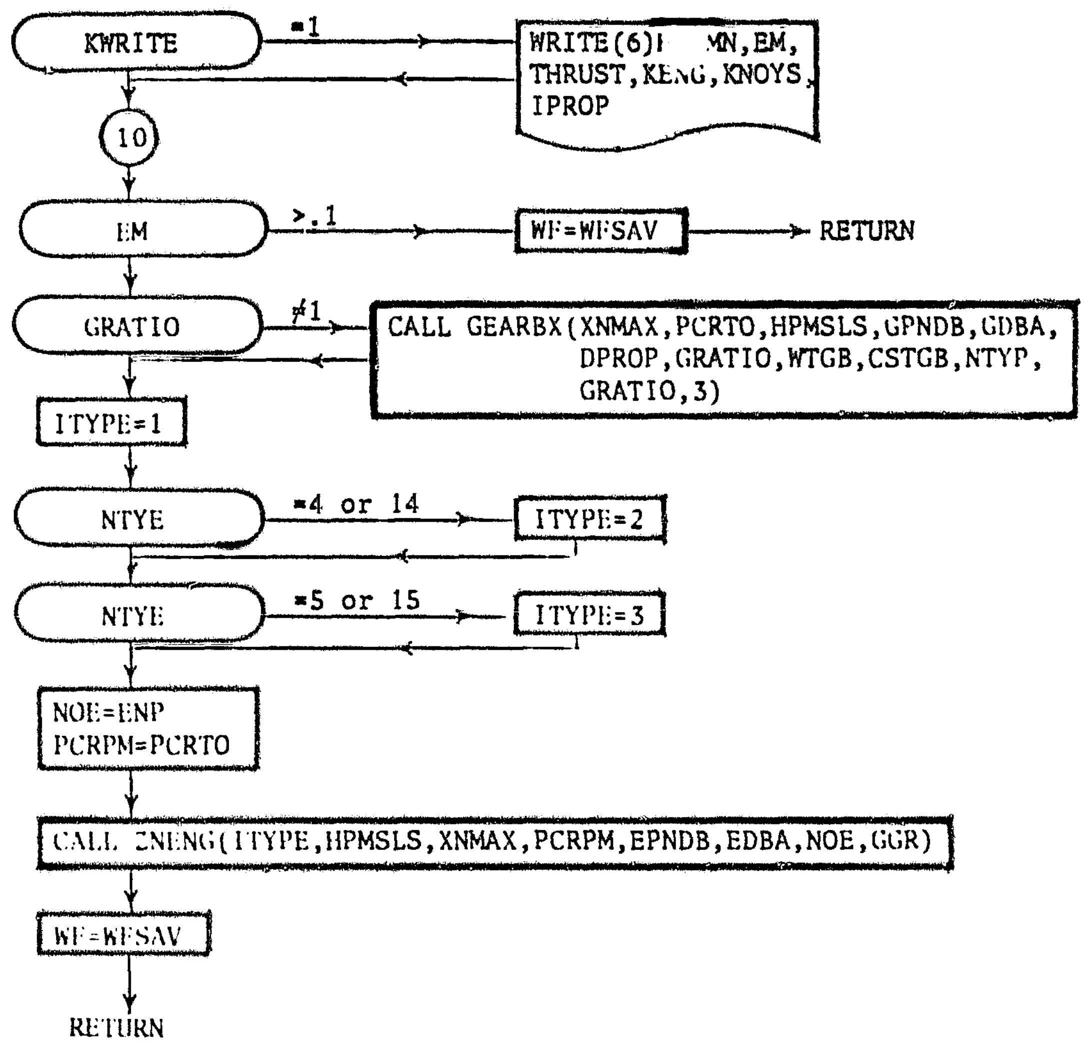


FIGURE IV.3.9 - DETAILED FLOWCHART, SUBROUTINE PNOYS PROPELLER DRIVEN AIRCRAFT NOISE CALCULATIONS


KWRITE
=1
WRITE(6)I MN,EM,
THRUST,KENG,KNOYS,
IPROP
10
EM
>.1
WF=WFSAV
RETURN
GRATIO
≠1
CALL GEARBX(XNMAX,PCRTO,HPMSLS,GPNDB,GDBA,
DPROP,GRATIO,WTGB,CSTGB,NTYP,
GRATIO,3)
ITYPE=1
NTYE
=4 or 14
ITYPE=2
NTYE
=5 or 15
ITYPE=3
NOE=ENP
PCRPM=PCRTO
CALL ENENG(ITYPE,HPMSLS,XNMAX,PCRPM,EPNDB,EDBA,NOE,GGR)
WF=WFSAV
RETURN

IV.3.2.7 Subroutine PWRPLT, Piston Engine Power and Fuel Flow. Subroutine PWRPLT computes piston engine power and fuel flow by the method of Section IV.1.2.3. The only subroutine called by PWRPLT is the utility routine ITRLN. A detailed flow chart for subroutine PWRPLT is presented in Figure IV.3.10.

PWRPLT

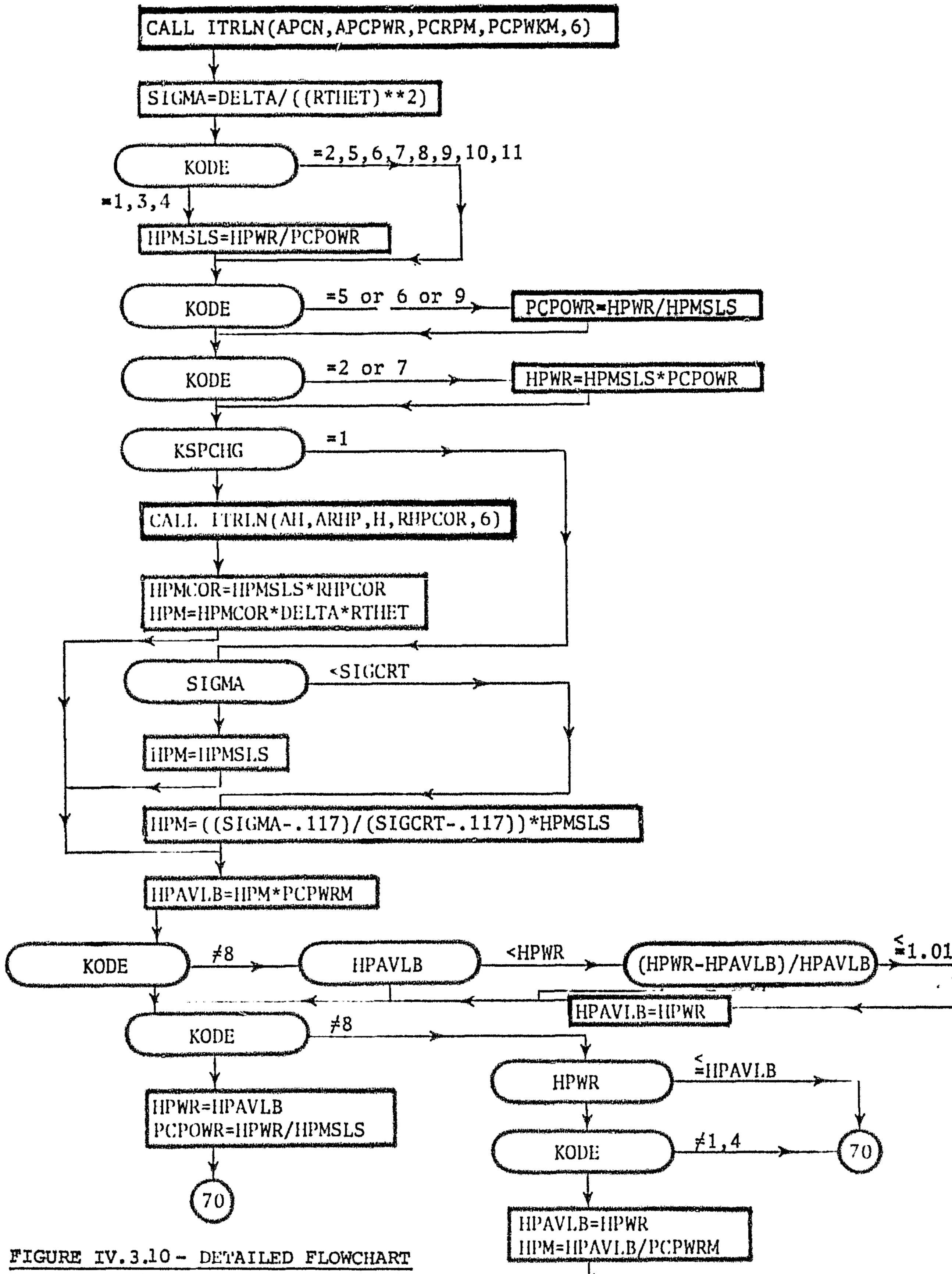
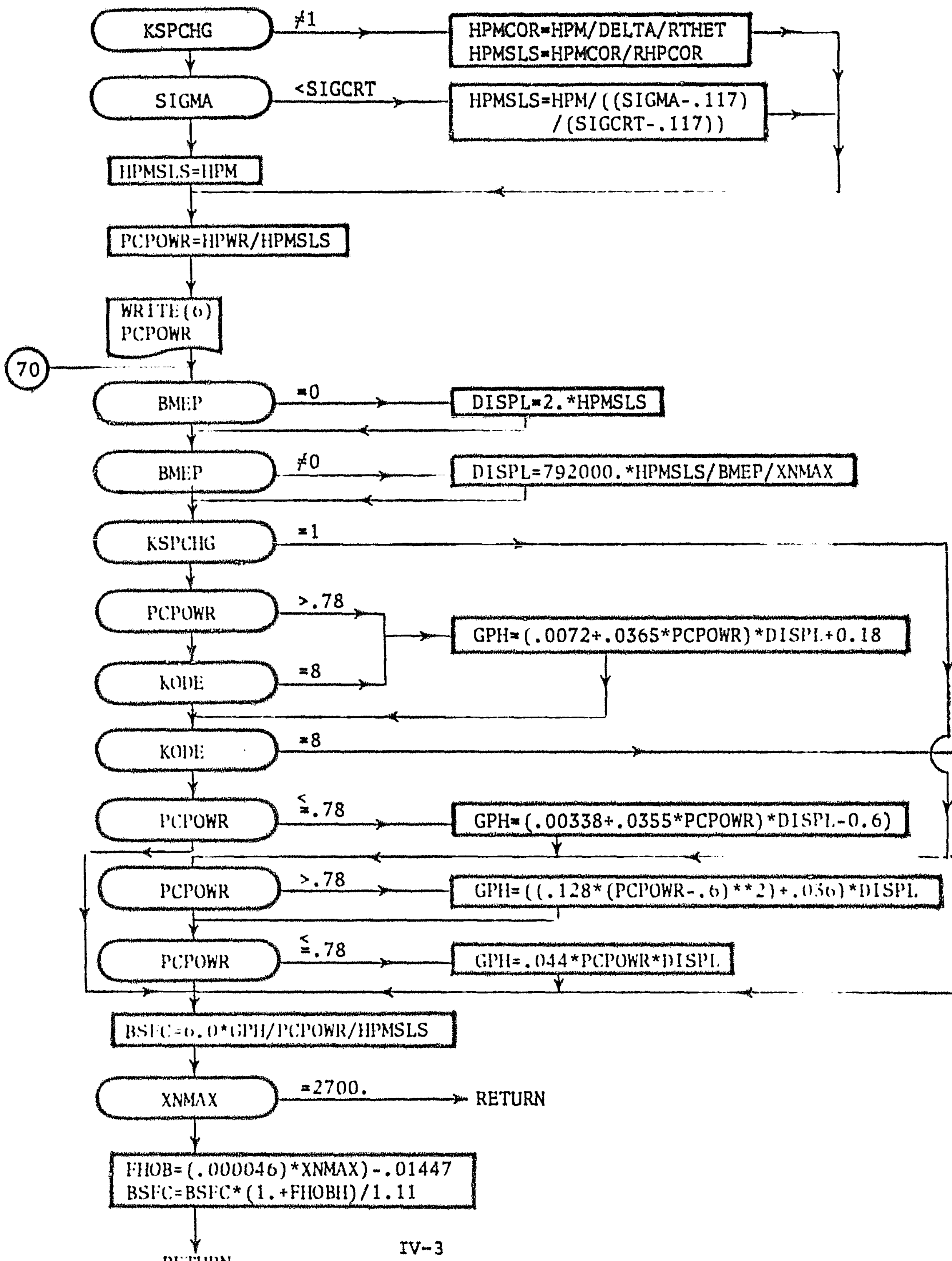


FIGURE IV.3.10 - DETAILED FLOWCHART SUBROUTINE PWRPLT, PISTON ENGINE POWER AND FUEL FLOW


KSPCHG
≠1
HPMCOR=HPM/DELTA/RTHET
HPMSLS=HPMCOR/RHPCOR
SIGMA
<SIGCRT
HPMSLS=HPM/((SIGMA-.117)
/(SIGCRT-.117))
HPMSLS=HPM
PCPOWR=HPWR/HPMSLS
WRITE(6)
PCPOWR
70
BMEP
=0
DISPL=2.*HPMSLS
BMEP
≠0
DISPL=792000.*HPMSLS/BMEP/XNMAX
KSPCHG
=1
PCPOWR
>.78
GPH=(.0072+.0365*PCPOWR)*DISPL+0.18
KODE
=8
KODE
=8
PCPOWR
≤.78
GPH=(.00338+.0355*PCPOWR)*DISPL-0.6)
PCPOWR
>.78
GPH=((.128*(PCPOWR-.6)**2)+.036)*DISPL
PCPOWR
≤.78
GPH=.044*PCPOWR*DISPL
BSFC=6.0*GPH/PCPOWR/HPMSLS
XNMAX
=2700.
RETURN
FHOB=(.000046)*XNMAX)-.01447
BSFC=BSFC*(1.+FHOBH)/1.11
RETURN

IV.3.2.8 Subroutine TURBEG, Turboprop Engine Performance. Subroutine TURBEG computes the performance of turboprop engines by the method of Section IV.1.2.4. The only subroutines called are the utility routines BIV (Section I.1.3.4); ITRLN (Section I.1.3.7); and ITRMHW (Section I.1.3.8). A detailed flow chart of TURBEG is presented in Figure IV.3.11.

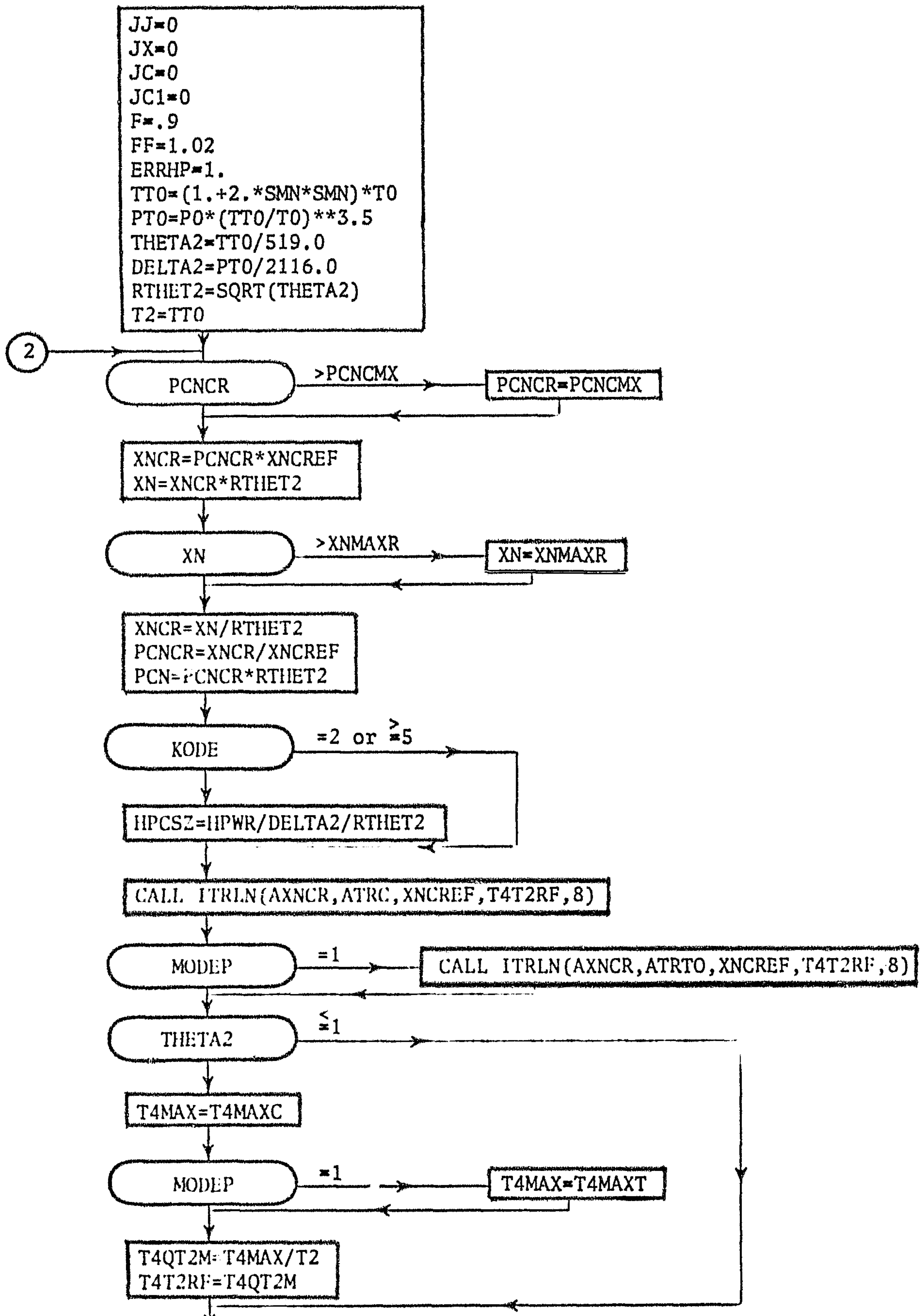
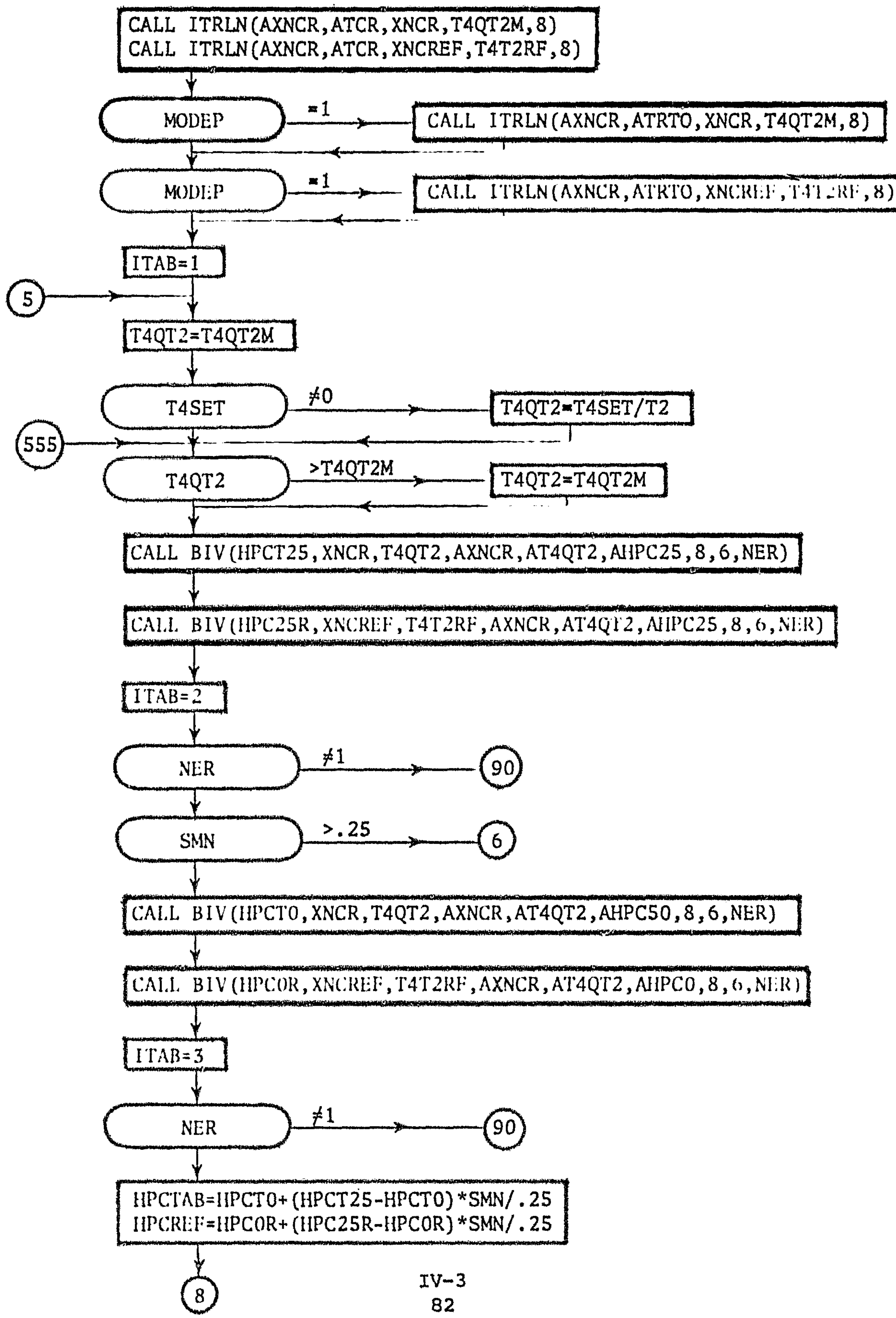
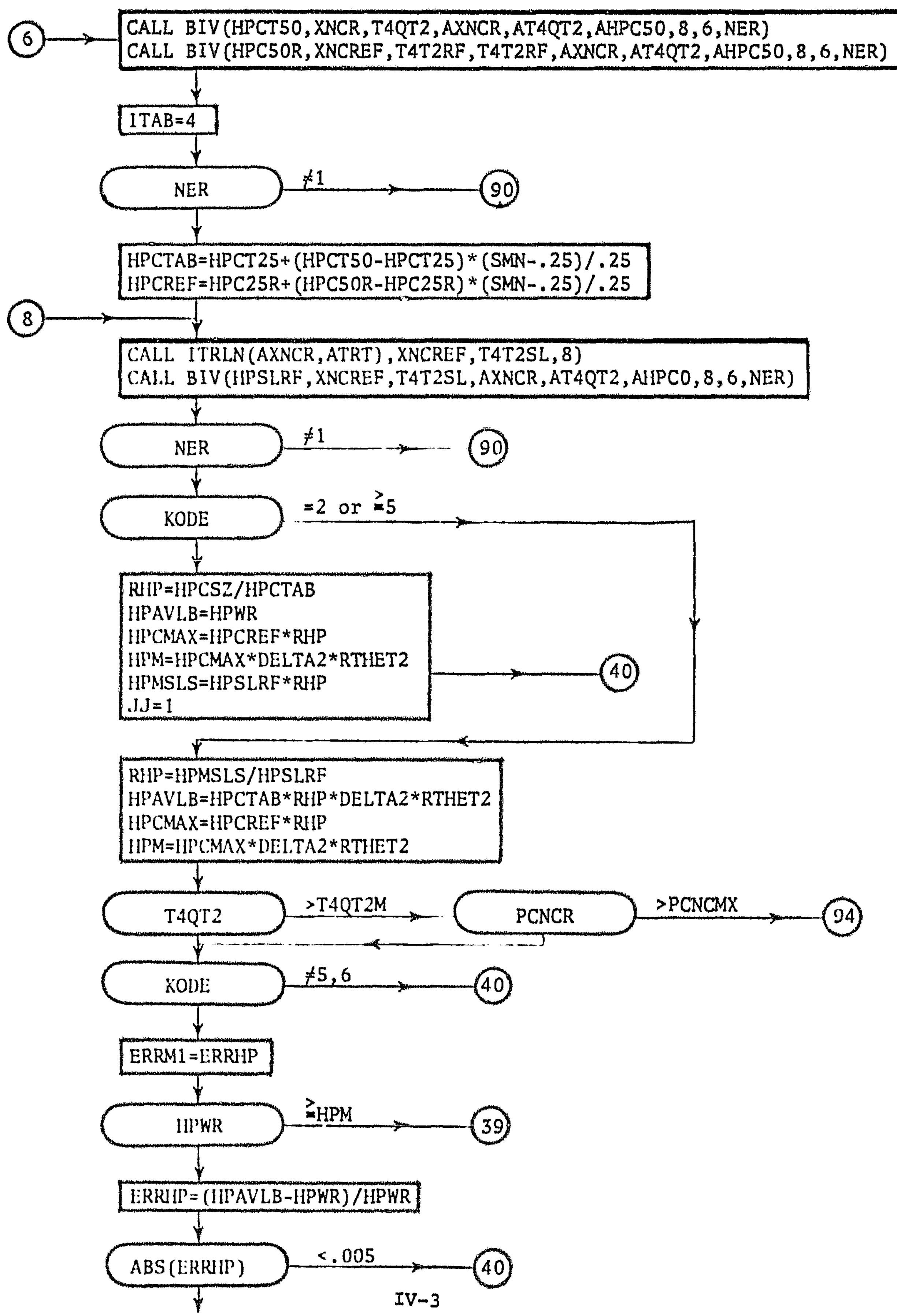
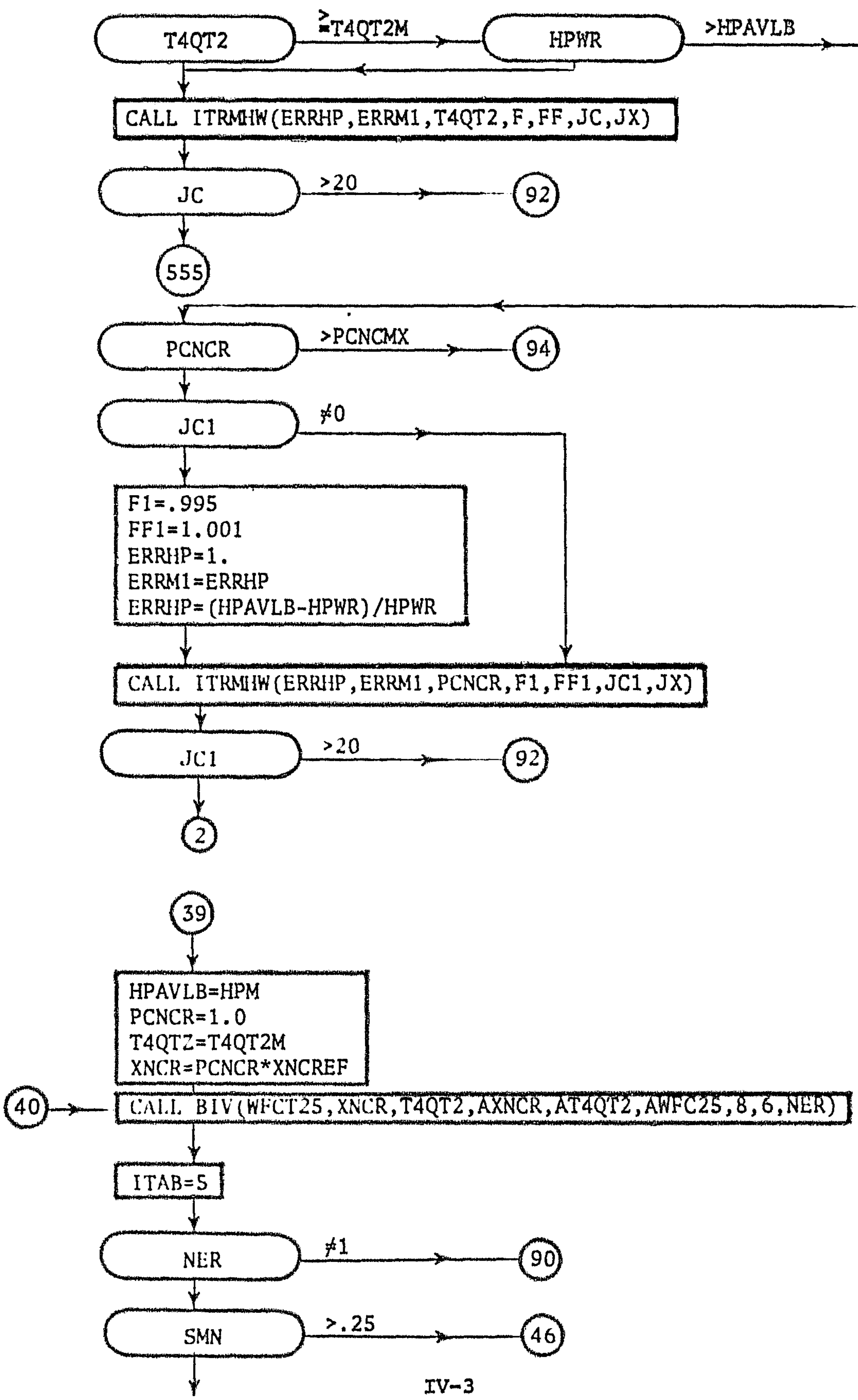
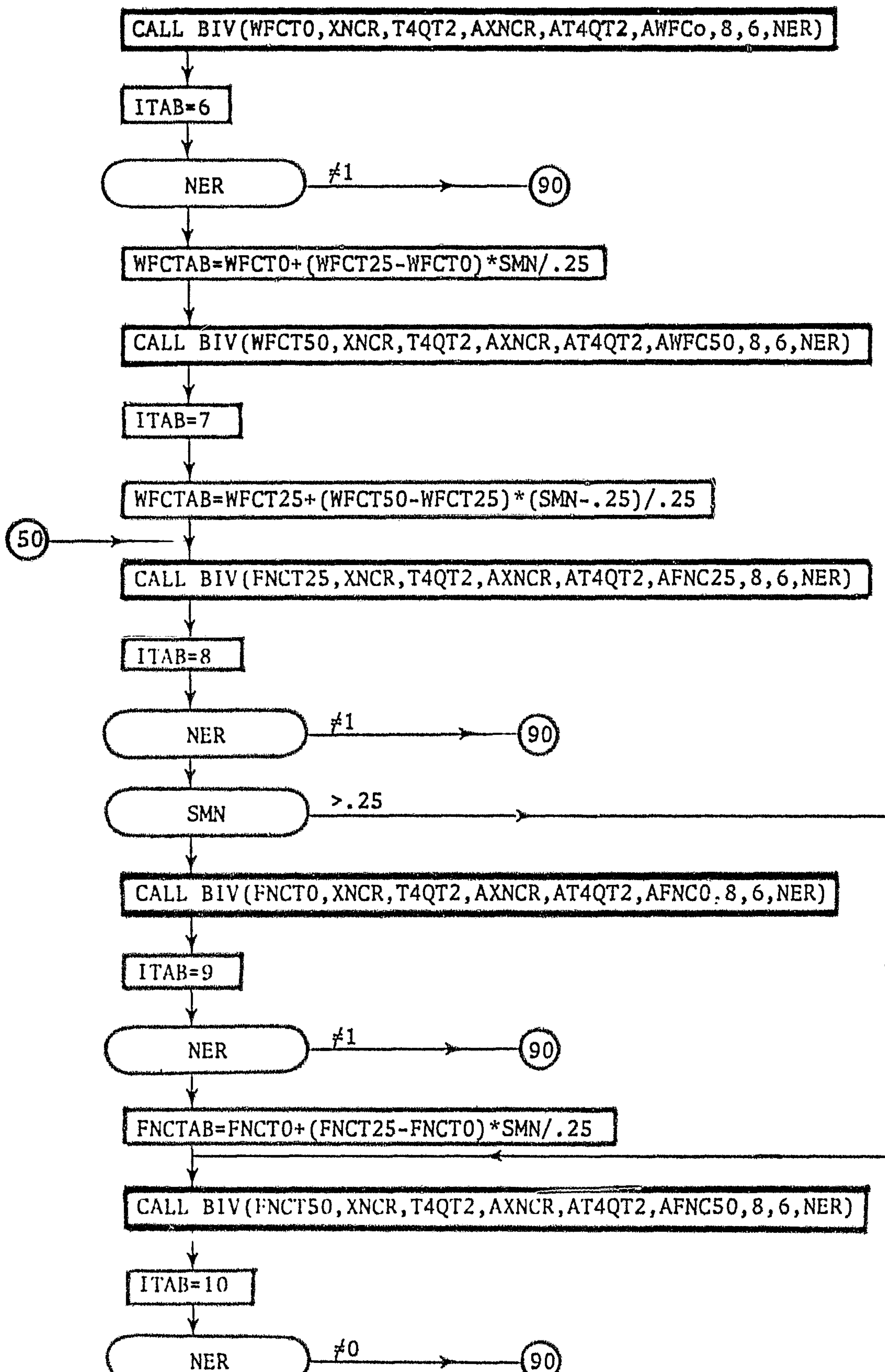


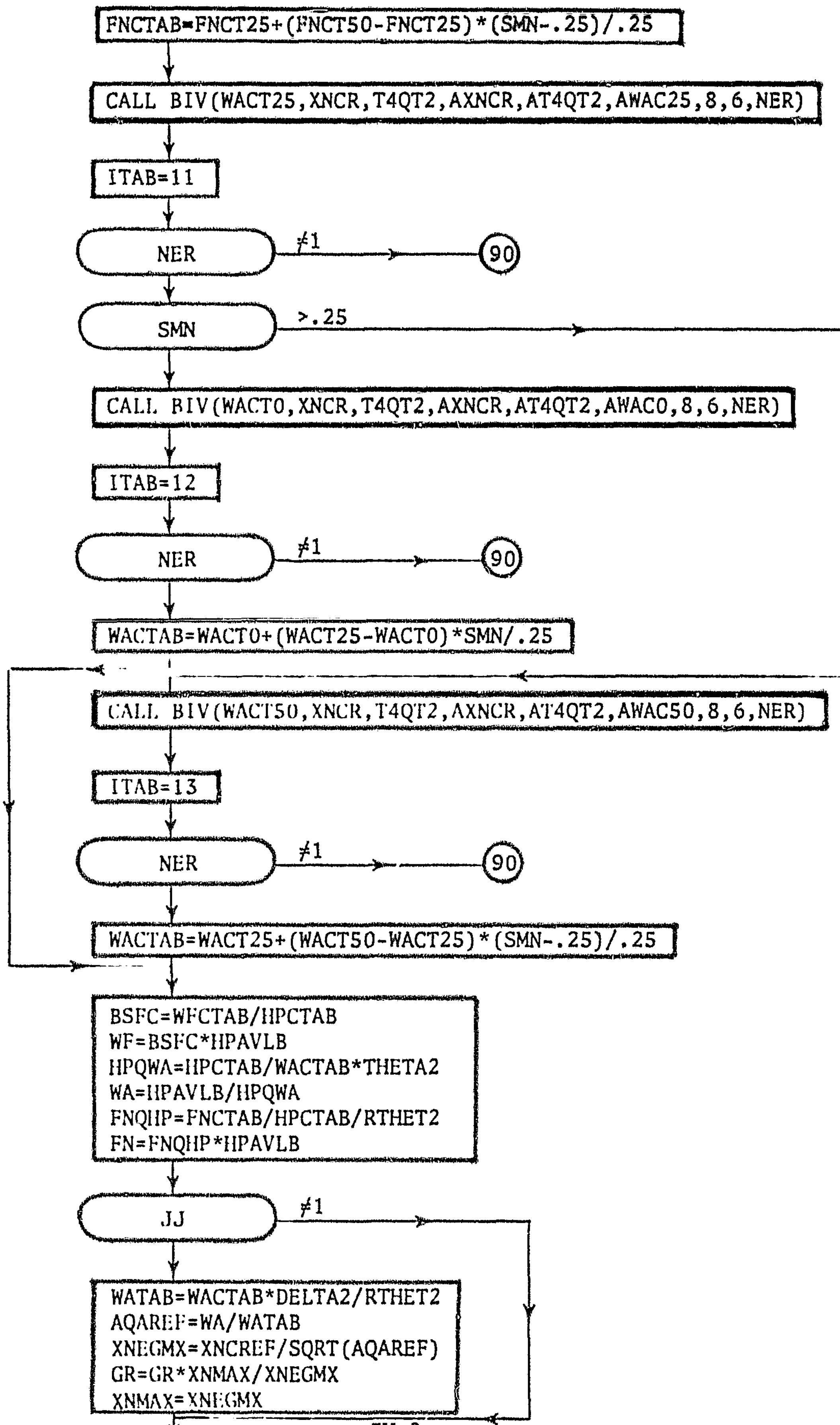
FIGURE IV.3.11 - DETAILED FLOWCHART, SUBROUTINE TURBEG

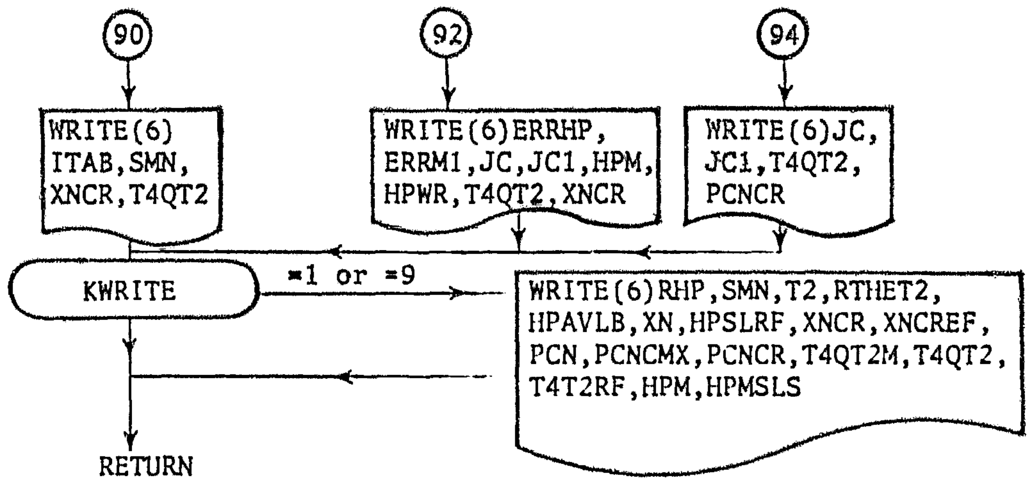

CALL ITRLN(AXNCR,ATCR,XNCR,T4QT2M,8)
CALL ITRLN(AXNCR,ATCR,XNCREF,T4T2RF,8)
MODEP
=1
CALL ITRLN(AXNCR,ATRTO,XNCR,T4QT2M,8)
MODEP
=1
CALL ITRLN(AXNCR,ATRTO,XNCREF,T4T2RF,8)
ITAB=1
5
T4QT2=T4QT2M
T4SET
≠0
T4QT2=T4SET/T2
555
T4QT2
>T4QT2M
T4QT2=T4QT2M
CALL BIV(HPCT25,XNCR,T4QT2,AXNCR,AT4QT2,AHPC25,8,6,NER)
CALL BIV(HPC25R,XNCREF,T4T2RF,AXNCR,AT4QT2,AHPC25,8,6,NER)
ITAB=2
NER
≠1
90
SMN
>.25
6
CALL BIV(HPCT0,XNCR,T4QT2,AXNCR,AT4QT2,AHPC50,8,6,NER)
CALL BIV(HPC0R,XNCREF,T4T2RF,AXNCR,AT4QT2,AHPC0,8,6,NER)
ITAB=3
NER
≠1
90
HPCTAB=HPCT0+(HPCT25-HPCT0)*SMN/.25
HPCREF=HPC0R+(HPC25R-HPC0R)*SMN/.25
8


6
CALL BIV(HPCT50,XNCR,T4QT2,AXNCR,AT4QT2,AHPC50,8,6,NER)
CALL BIV(HPC50R,XNCREF,T4T2RF,T4T2RF,AXNCR,AT4QT2,AHPC50,8,6,NER)
ITAB=4
NER
≠1
90
HPCTAB=HPCT25+(HPCT50-HPCT25)*(SMN-.25)/.25
HPCREF=HPC25R+(HPC50R-HPC25R)*(SMN-.25)/.25
8
CALL ITRLN(AXNCR,ATRT),XNCREF,T4T2SL,8)
CALL BIV(HPSLRF,XNCREF,T4T2SL,AXNCR,AT4QT2,AHPC0,8,6,NER)
NER
≠1
90
KODE
=2 or ≥5
RHP=HPCSZ/HPCTAB
HPAVLB=HPWR
HPCMAX=HPCREF*RHP
HPM=HPCMAX*DELTA2*RTHET2
HPMSLS=HPSLRF*RHP
JJ=1
40
RHP=HPMSLS/HPSLRF
HPAVLB=HPCTAB*RHP*DELTA2*RTHET2
HPCMAX=HPCREF*RHP
HPM=HPCMAX*DELTA2*RTHET2
T4QT2
>T4QT2M
PCNCR
>PCNCMX
94
KODE
≠5,6
40
ERRM1=ERRHP
HPWR
≥HPM
39
ERRHP=(HPAVLB-HPWR)/HPWR
ABS(ERRHP)
<.005
40


T4QT2
≥T4QT2M
HPWR
>HPAVLB
CALL ITRMHW(ERRHP,ERRM1,T4QT2,F,FF,JC,JX)
JC
>20
92
555
PCNCR
>PCNCMX
94
JC1
≠0
F1=.995
FF1=1.001
ERRHP=1.
ERRM1=ERRHP
ERRHP=(HPAVLB-HPWR)/HPWR
CALL ITRMHW(ERRHP,ERRM1,PCNCR,F1,FF1,JC1,JX)
JC1
>20
92
2
39
HPAVLB=HPM
PCNCR=1.0
T4QTZ=T4QT2M
XNCR=PCNCR*XNCREF
40
CALL BIV(WFCT25,XNCR,T4QT2,AXNCR,AT4QT2,AWFC25,8,6,NER)
ITAB=5
NER
≠1
90
SMN
>.25
46


CALL BIV(WFCTO,XNCR,T4QT2,AXNCR,AT4QT2,AWFCo,8,6,NER)
ITAB=6
NER
≠1
90
WFCTAB=WFCTO+(WFCT25-WFCTO)*SMN/.25
CALL BIV(WFCT50,XNCR,T4QT2,AXNCR,AT4QT2,AWFC50,8,6,NER)
ITAB=7
WFCTAB=WFCT25+(WFCT50-WFCT25)*(SMN-.25)/.25
50
CALL BIV(FNCT25,XNCR,T4QT2,AXNCR,AT4QT2,AFNC25,8,6,NER)
ITAB=8
NER
≠1
90
SMN
>.25
CALL BIV(FNCTO,XNCR,T4QT2,AXNCR,AT4QT2,AFNCO,8,6,NER)
ITAB=9
NER
≠1
90
FNCTAB=FNCTO+(FNCT25-FNCTO)*SMN/.25
CALL BIV(FNCT50,XNCR,T4QT2,AXNCR,AT4QT2,AFNC50,8,6,NER)
ITAB=10
NER
≠0
90


FNCTAB=FNCT25+(FNCT50-FNCT25)*(SMN-.25)/.25
CALL BIV(WACT25,XNCR,T4QT2,AXNCR,AT4QT2,AWAC25,8,6,NER)
ITAB=11
NER
≠1
90
SMN
>.25
CALL BIV(WACT0,XNCR,T4QT2,AXNCR,AT4QT2,AWAC0,8,6,NER)
ITAB=12
NER
≠1
90
WACTAB=WACT0+(WACT25-WACT0)*SMN/.25
CALL BIV(WACT50,XNCR,T4QT2,AXNCR,AT4QT2,AWAC50,8,6,NER)
ITAB=13
NER
≠1
90
WACTAB=WACT25+(WACT50-WACT25)*(SMN-.25)/.25
BSFC=WFCTAB/HPCTAB
WF=BSFC*HPAVLB
HPQWA=HPCTAB/WACTAB*THETA2
WA=HPAVLB/HPQWA
FNQHP=FNCTAB/HPCTAB/RTHET2
FN=FNQHP*HPAVLB
JJ
≠1
WATAB=WACTAB*DELTA2/RTHET2
AQAREF=WA/WATAB
XNEGMX=XNCREF/SQRT(AQAREF)
GR=GR*XNMAX/XNEGMX
XNMAX=XNEGMX


90
92
94
WRITE(6) ITAB,SMN, XNCR,T4QT2
WRITE(6)ERRHP, ERRM1,JC,JC1,HPM, HPWR,T4QT2,XNCR
WRITE(6)JC, JC1,T4QT2, PCNCR
KWRITE
=1 or =9
WRITE(6)RHP,SMN,T2,RTHET2, HPAVLB,XN,HPSLRF,XNCR,XNCREF, PCN,PCNCMX,PCNCR,T4QT2M,T4QT2, T4T2RF,HPM,HPMSLS
RETURN

IV.3.2.9 Subroutine WAIT, Propeller Weight. Subroutine WAIT computes propeller weights by the method of Section IV.1.3.4. The indicator IWTCON determines which one of five sets of equations are used to predict 1970 and 1980 propeller weights. No other subroutines are called by WAIT. A detailed flow chart for subroutine WAIT is provided in Figure IV.3.12.

WAIT

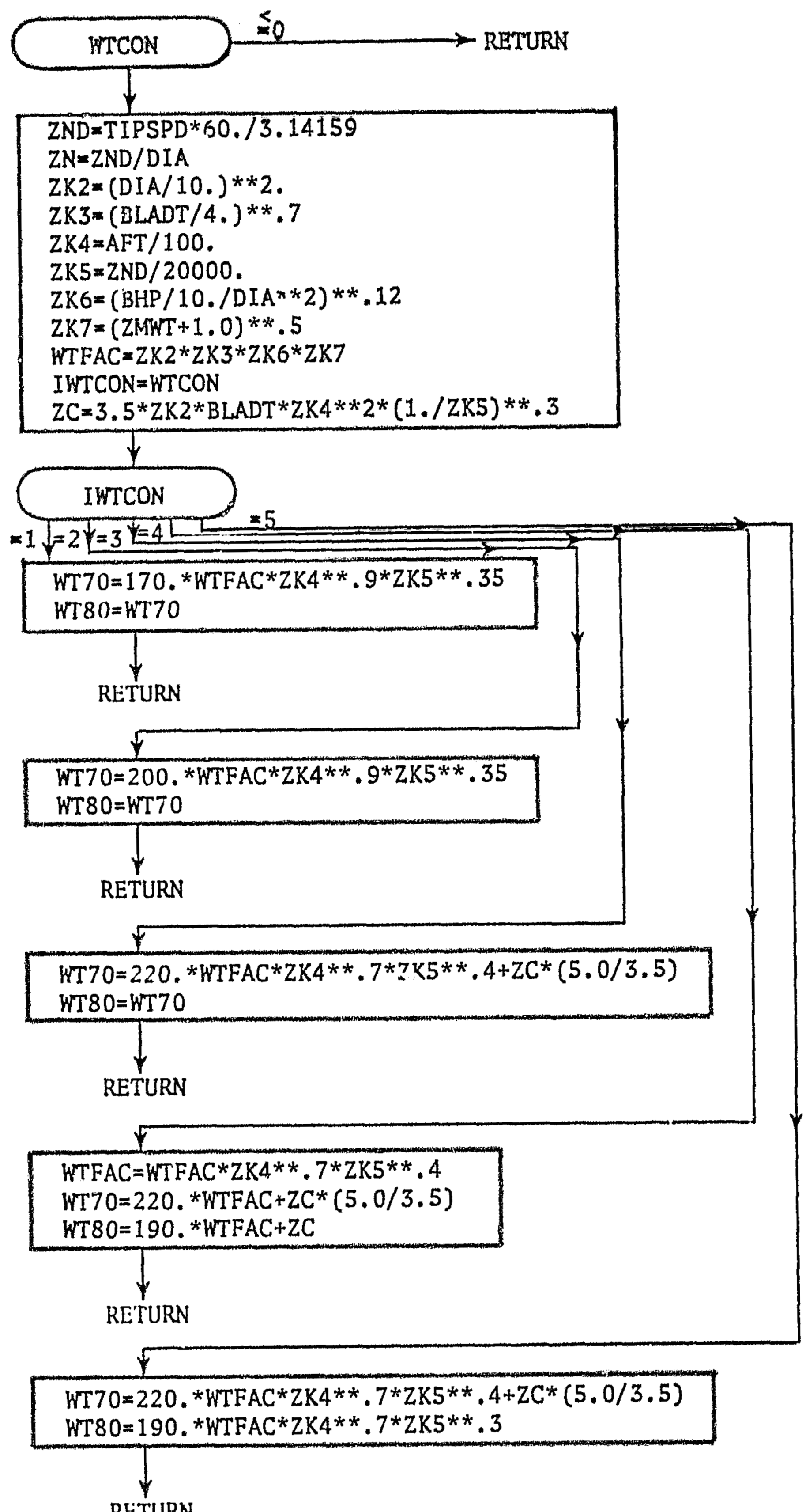


FIGURE IV.3.12 - DETAILED FLOWCHART, SUBROUTINE WAIT - PROPELLER WEIGHTS

IV.3.2.10 <u>Subroutine ZNENG, Engine Noise</u>. This routine computes piston, rotary, and turboshaft engine noise characteristics by the method of Section IV.1.3.7. Engine type is selected by the indicator ITYPE. The only subroutine called by ZNENG is the utility routine UNINT (Section I.1.3.17). A detailed flow chart for subroutine ZNENG is presented in Figure IV.3.13.

ZNENG

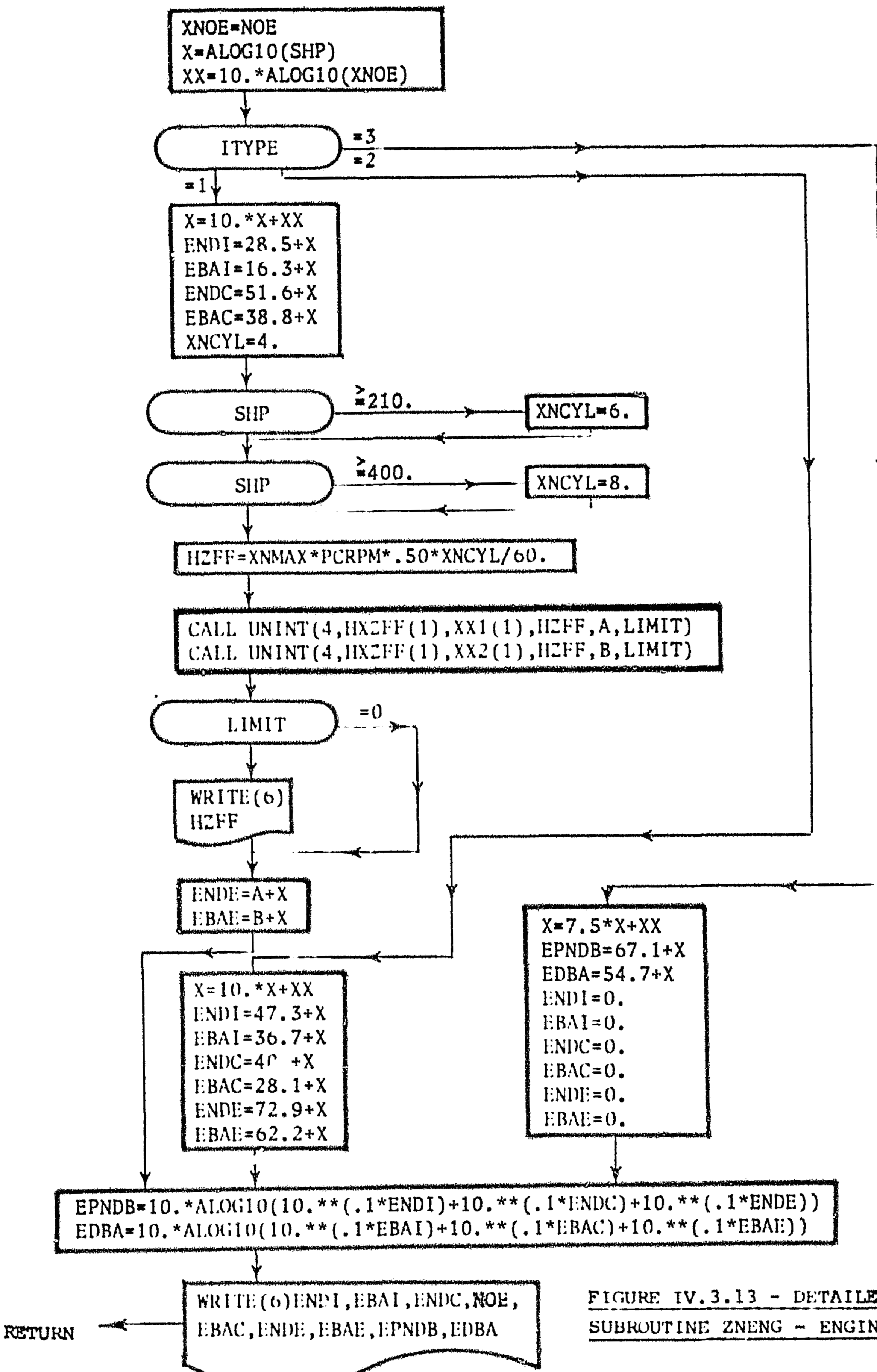


FIGURE IV.3.13 - DETAILED FLOWCHART, SUBROUTINE ZNENG - ENGINE NOISE

IV.3.2.11 Subroutine ZNOISE, Propeller Noise. This routine computes propeller generated noise by the method of Section IV.1.3.5. The only subroutine called is the utility routine BILINE (Section I.1.3.1). A detailed flow chart for subroutine ZNOISE is presented in Figure IV.3.14.

ZNOISE

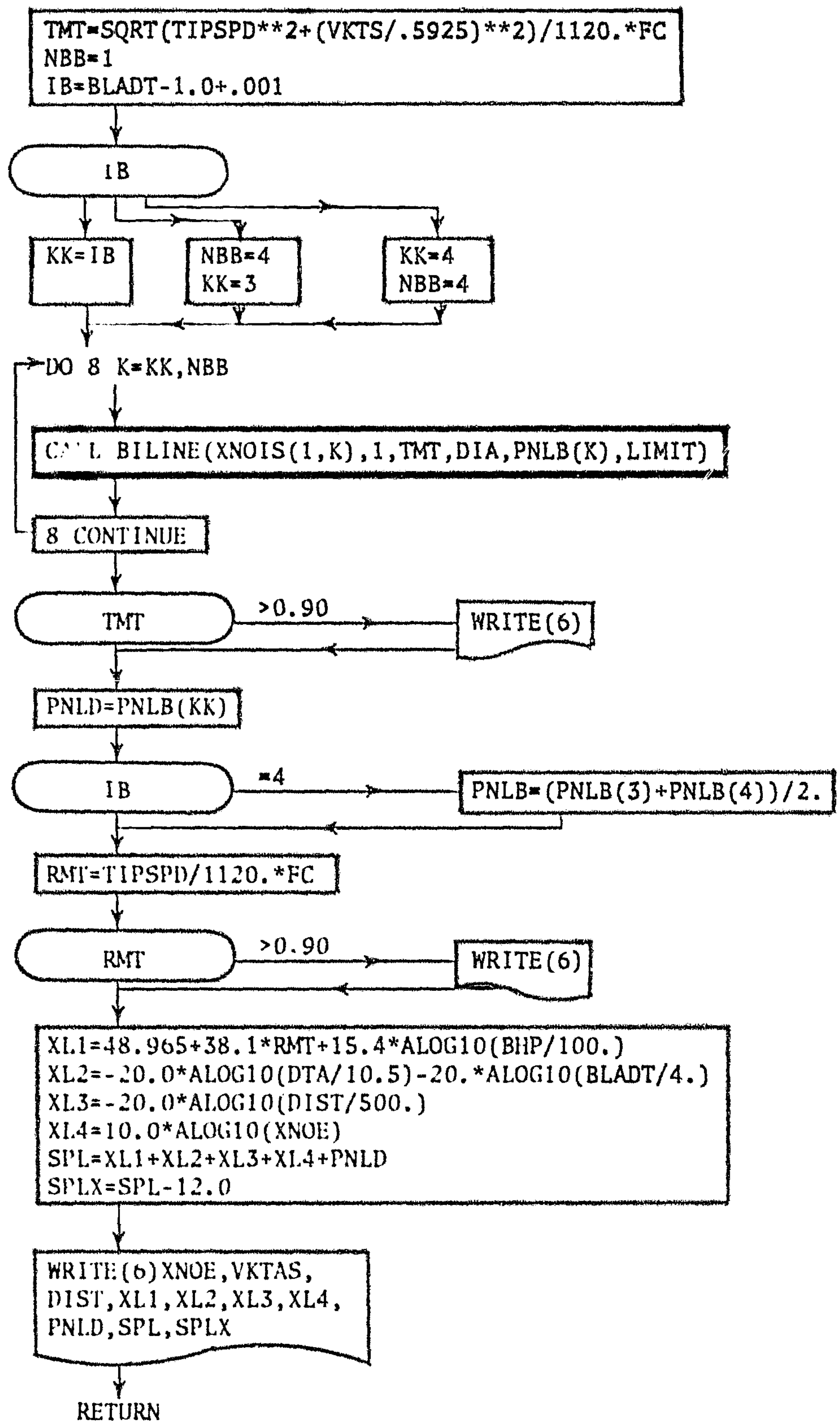


FIGURE IV.3.14 - DETAILED FLOWCHART, SUBROUTINE ZNOISE - PROPELLER NOISE

IV.3.2.12 Subroutine COST, Propeller Costs. This routine computes propeller costs by the method of Section IV.1.3.2. Both 1970 or 1980 cost estimates may be made. No subroutines are called by cost. A detailed flow chart for subroutine COST is presented in Figure IV.3.15.

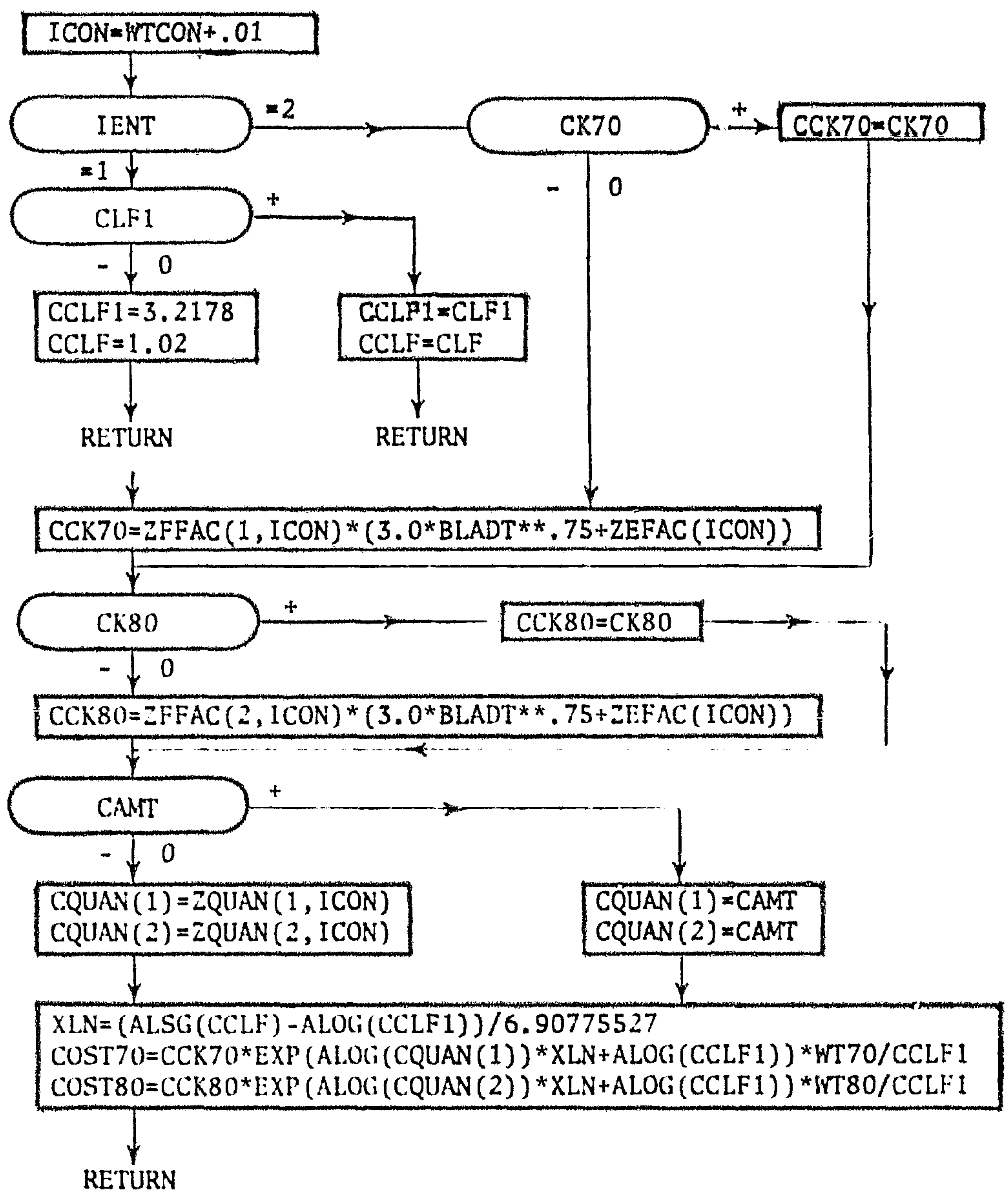


FIGURE IV.3.15 - DETAILED FLOWCHART, SUBROUTINE COST--
PROPELLER COSTS

IV.3.2.13 Subroutines ENGDTT, ENGDT1 to ENGDT7

These routines provice propulsion engine characteristics for various turbojet engines. A detailed flowchart is presented for ENGDT1. The engines described by these routines are listed in Section IV.1.1.2.

ENGD.T1- TURBOJET VERSION

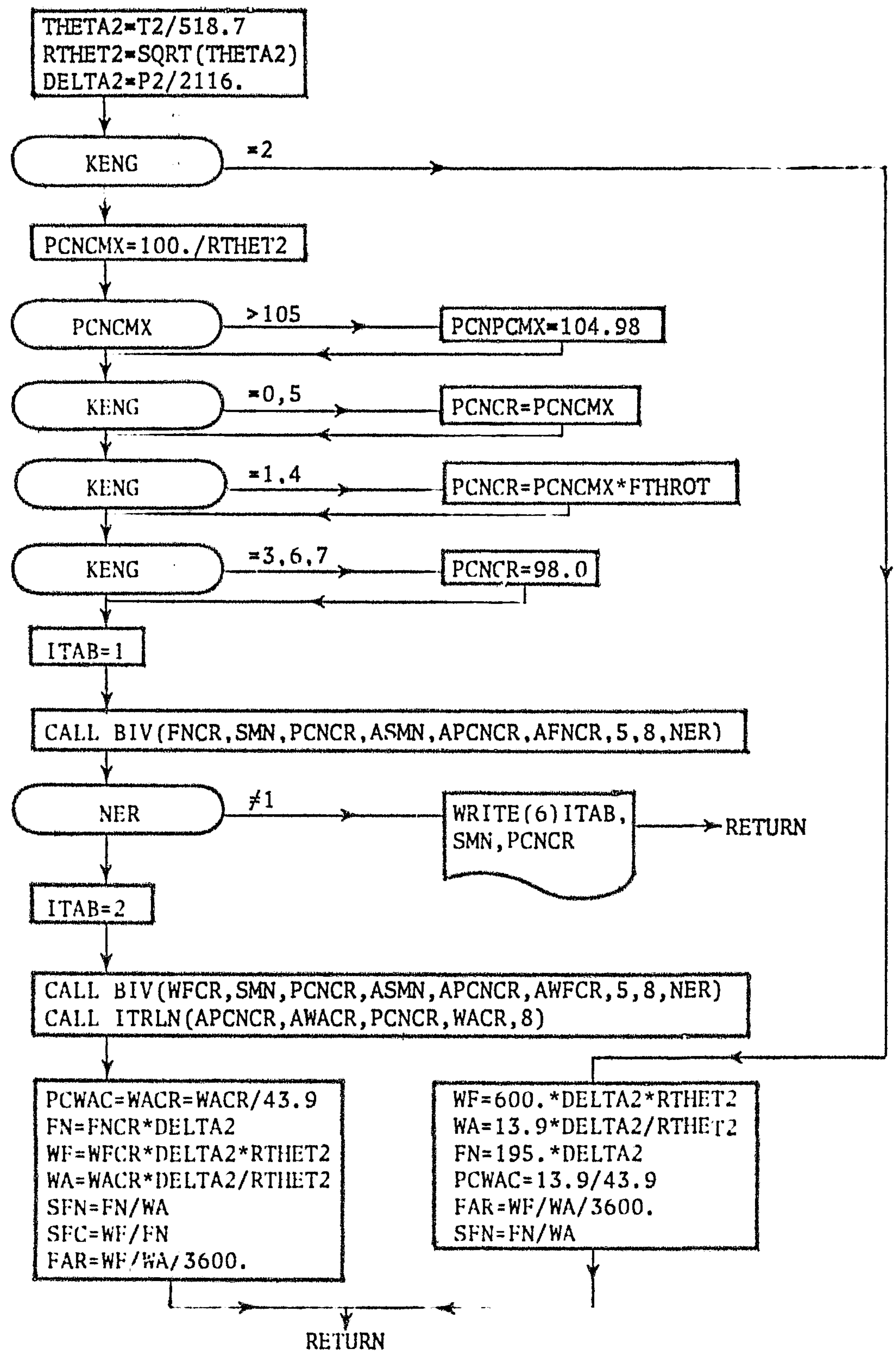


FIGURE IV.3.16- DETAILED FLOWCHART, SUBROUTINE ENGDT1